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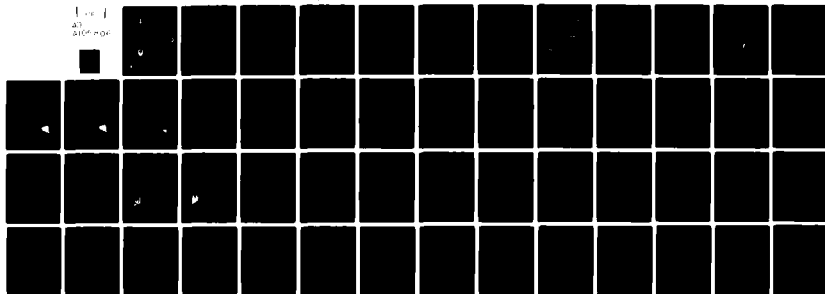
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TERRAIN MASKING ANALYSIS  
FOR WHITE SANDS MISSILE RANGE  
EAST CENTER 50 AND WEST CENTER 50

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**U.S. ARMY MISSILE COMMAND**  
Redstone Arsenal, Alabama 35898

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) An analysis was made of terrain masking for selected ground radar test locations at White Sands Missile Range. Digitized terrain altitude data are reformatted to allow calculation of straight line masking along radial profiles from the radar site. These data are then displayed in the form of maps of the illuminated terrain and altitude profiles.		

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## I. INTRODUCTION

A recent test involving an air defense missile system required the consideration of low altitude target detectability and clutter and multipath effects for both the ground-based fire control radar and the missile RF seeker. A visit to the test site at White Sands Missile Range (WSMR), New Mexico, and discussions with personnel familiar with the area suggested that the targets might indeed be flown below the radar horizon in some regions of interest, and that portions of the terrain, masked from the radar or seeker, might change clutter and multipath predictions.

An initial analysis was done using contour maps of the region, followed by a visit to the site. These two approaches did not exactly agree, since the on-site examination indicated a more severe problem than predicted from the contour maps. This may have been due to difficulty in comparing the contour data representing fairly large intervals to the visual impact of the site. Some difficulty was noted, however, in comparing the map features with the actual terrain. In any event, a more exact method was required and the availability of digitized terrain elevation data suggested a computer masking analysis.

A set of computer programs was implemented to reformat the data and perform a line-of-sight masking analysis. This document presents the results of a radar masking investigation of two separate locations at WSMR. Described in the following sections are the terrain type and location, and data analysis and manipulation. Results are presented in the form of ground masking plots. A sample computer program is included in the Appendix.

## II. DESCRIPTION OF TERRAIN

The testing area is located within the White Sands Missile Range, New Mexico. The two radar locations considered are marked EAST CENTER 50 (EC 50) and WEST CENTER 50 (WC 50) on the map of Figure 1. The sector of interest was roughly rectangular in shape and bounded by  $106^{\circ}16'$  and  $106^{\circ}26'$  longitude, and  $33^{\circ}8'$  and  $33^{\circ}25'$  latitude. These limits are indicated in Figure 1. Target flights were to be, in general, along north-south paths within this region. The locations of the two sites, as used in the analysis, are given in Table 1.

Table 1. Radar Locations

Location	Longitude	Latitude
EC 50	$106^{\circ}17'31''$	$33^{\circ}8'21''$
WC 50	$106^{\circ}26'11.5''$	$33^{\circ}8'43''$

The surface characteristics of the test site region were described in three forms:

- Visual from a visit to the site



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- Geological survey topographic maps
- Defense Mapping Agency (DMA) terrain altitudes on magnetic tape.

Each data source aided in estimating the radar coverage.

Gross terrain features are indicated in Figure 1. The terrain for both sites is gently rolling to flat within most of the test region. A Malpais region exists to the north, with the San Andres Mountains to the northwest. A dry stream bed runs north to south over part of the western edge of the area. A gentle rise was visually noted at 5 or 6 miles from the radar site at EC 50 and appeared to mask much of the terrain in the test area. This was not evident on the contour map and led to concern over the extent of masking and other possible "hidden" regions. These questions led to the analysis of DMA digitized terrain data on a CYBER 74 digital computer.

### III. MASKING ANALYSIS

The DMA terrain data consisted of terrain elevation above mean sea level (MSL) truncated to the nearest meter. The data files are arranged into 1-degree by 1-degree geographic areas, with each file containing samples falling into a single 1-degree square. The reference for each file is the southwest corner of the degree square. Each file contains 1200 data records, each having a constant longitude value. The first value in each record is the southernmost elevation within the square; the last value is the northernmost elevation. Each such record contains 1200 values so that the terrain elevation is sampled on 3-second intervals in longitude and latitude. On an earth model with a 4,000-foot MSL elevation, this sample spacing is approximately 250 feet in longitude and 300 feet in latitude for the region of interest. These data require several transformations to be useful for a radar terrain analysis.

Consider the radar radial elevation cut of Figure 2. Transformation of the terrain elevation to radial elevation cuts allows a rather simple algorithm to search for the masked regions, shown as shaded areas, and to store the start and stop ranges of masking. Repeated radial profiles then produce a map similar to Figure 3 where the shaded regions now represent the surface area illuminated by the radar. The negative of this presentation could also be used to represent the masked area.

The data transformation and manipulations required are listed below:

- Transformation from geodetic coordinates (latitude, longitude, elevation) to geocentric coordinates ( $X_c$ ,  $Y_c$ ,  $Z_c$ ).
- Transformation from geocentric coordinates ( $X_c$ ,  $Y_c$ ,  $Z_c$ ) to tangent plane coordinates through a point on or above the surface.
- Reverse order the data left to right (EC 50 only).
- Interpolate in three dimensions to produce radial elevation profiles.
- Masking algorithm along radial elevation profiles to locate masked regions.

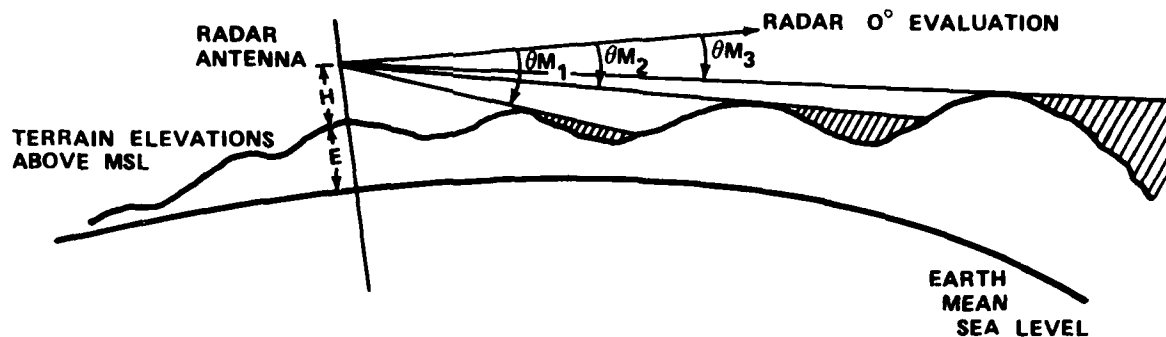


Figure 2. Radar masking definitions.

- Graphic presentation of results.

The two transformation algorithms were taken from Reference [1] and applied directly to the data. No difficulties were encountered; however, it should be noted that the Cartesian systems are "left-handed." For example, in the tangent plane system, the X-axis lies along a north-south line through the tangent point and is positive north of the point; Z is altitude normal to the tangent plane and positive up; and Y is positive to the east. The ellipsoidal earth model used was the Clarke Spheroid of 1866 with semi-major axis 20,925,832,136' and eccentricity (e) 0.0822718536.

Item 3, reversal of the data, is required for EC 50 due to the order of the data. The DMA data start in the southwest corner of the region, hence the regions at longest range from the radar appear first on the tape. The data were reordered such that near ranges were physically located first on the data file. The interpolation routine could then read a pair of records, perform the required interpolation to convert X, Y, Z to range, azimuth, elevation, store these values, and read in the next set of elevation data. The mask algorithm was then used to search along constant azimuth profiles for hidden elevation regions and the results plotted with routines developed locally and reported in Reference [2].

The WC 50 data did not require reversal, so Item 3 was not used. The remainder of the analysis was identical.

#### IV. RESULTS

The graphic presentations of radar masking resulting from this analysis are given in two forms: the range-azimuth "map" described earlier, plus a series of elevation profiles to aid in interpretation of the map and estimation of masked flight altitudes for the targets. Three radar altitudes of interest are also presented; each represents the height of the radar antenna center above the local terrain. Figures 4, 5, and 6 are maps for EC 50 of illuminated regions for the three heights for the azimuth coverage of  $-5^{\circ}$  to  $-70^{\circ}$ . Range

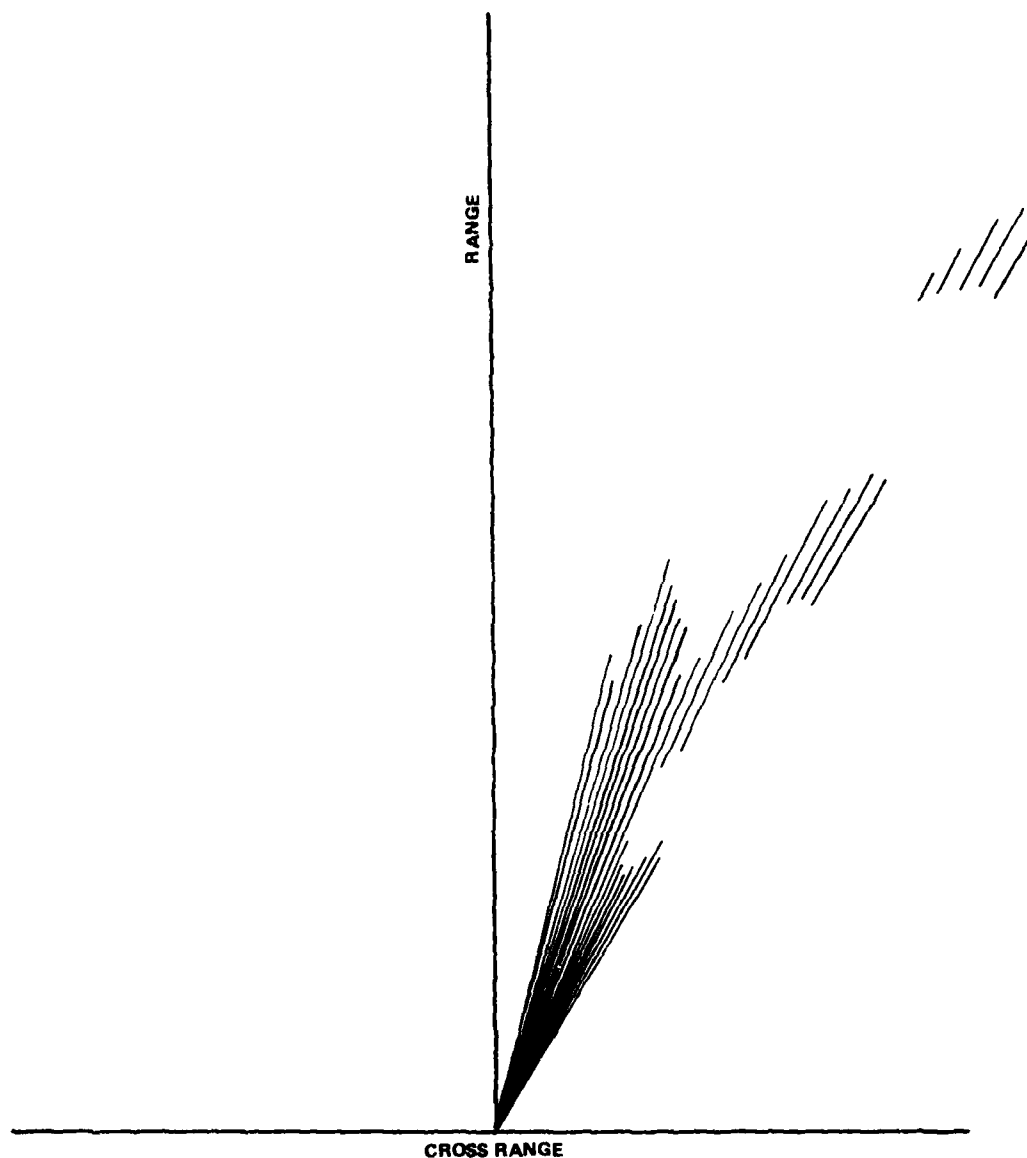


Figure 3. Masking Diagram

coverage was 0 to 100,000 feet, with the cross range dimension limited to 70,000 feet for this presentation. Azimuth increments were 1 degree; range increments 50 feet.

As expected, reduction of antenna height significantly reduces the illuminated terrain area. Clutter would be reduced somewhat for medium ranges, but the mountain ranges at long range might still produce significant clutter.

Radial elevation profiles for EC 50 are presented in Figures 7 through 19 for the 40-foot radar altitude only. Other altitudes may be investigated by

shifting the left hand altitude scale. The mountains appear quite abrupt due to the difference in scale factors on the two axes. Also, note the "tilt" of flat areas due to earth curvature. In the region  $-20^{\circ}$  to  $-40^{\circ}$  a target would have to be below 75 feet to 100 feet altitude for a 40-foot radar altitude in order to be masked, and then only at ranges of 55 to 65 kilofeet; however, for a 9-foot radar altitude, the same target would be masked at about 125 feet altitude. These boundary altitudes between masked and unmasked could be significantly higher when vegetation is added to the terrain and other propagation problems are considered.

A similar set of data for WC 50 is given in Figures 20 through 36. For this location, only the 9-foot antenna height was used, and an investigation of clutter fences was done for this site. Figures 20 and 21 are illuminated regions in two scale factors without the fence, while Figures 22 and 23 show the effects of a circular section clutter fence whose location was 100 feet from the radar and whose top was the same as the antenna feed, 9 feet. The reduction of close-in illuminated area is significant, without noticed increase in long-range masking. Figures 24 through 36 are radial altitude profile cuts similar to those for EC 50.

Note that in Figures 20 through 23, the algebraic sign of the cross range axis has been changed to facilitate plotting. The sign conventions of section 3 were used in developing the figure.

The possibility of terrain masking of low altitude targets is lower for this site. For most of the sector, the long range clutter problem has been significantly reduced since the long range mountain slopes only appear almost due north from the site. In this sense, WC 50 presents a more typical clutter environment than EC 50.

Some caution should be exercised in using the results, in particular the clutter fence data. The computer algorithm calculated line-of-sight masking in which the edge diffraction effects were ignored. Therefore, to a certain extent, many of the shadow regions will be partially illuminated. This is believed to be an insignificant effect for the terrain masking, since many other factors, such as surface roughness and vegetation, will reduce the abruptness of the edge. This is not the case for the conducting clutter fence. A recent analysis of this problem [3] indicates that no more than a few dB's reduction of the clutter energy should be expected for this geometry. Therefore, the clutter fence was not constructed and no evaluation is possible.

## V. CONCLUSIONS

The slight rise evident from visual inspection was quite obvious on the DMA data and did mask much of the region from 20 kilofeet range out to the mountains at 60 to 80 kilofeet for EC 50. This feature is not that evident on the contour maps, so that the computer analysis did predict some of the masking evident in actual flights. Target altitudes for masking did not agree as well as expected, but vegetation effects were not included in this analysis and the precision of reported target altitude is unknown.

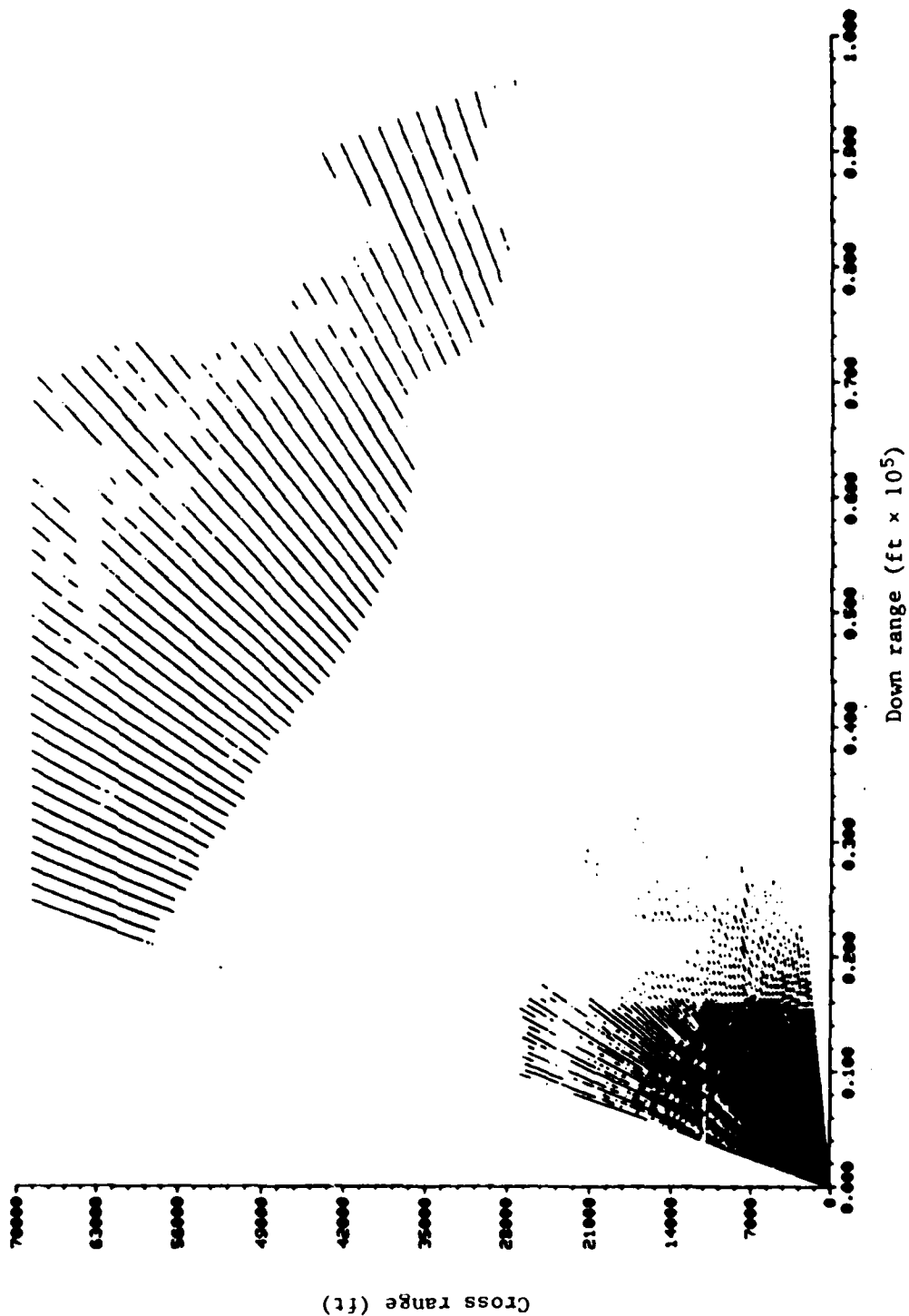


Figure 4. Illuminated region from EC 50, 40-foot radar height.

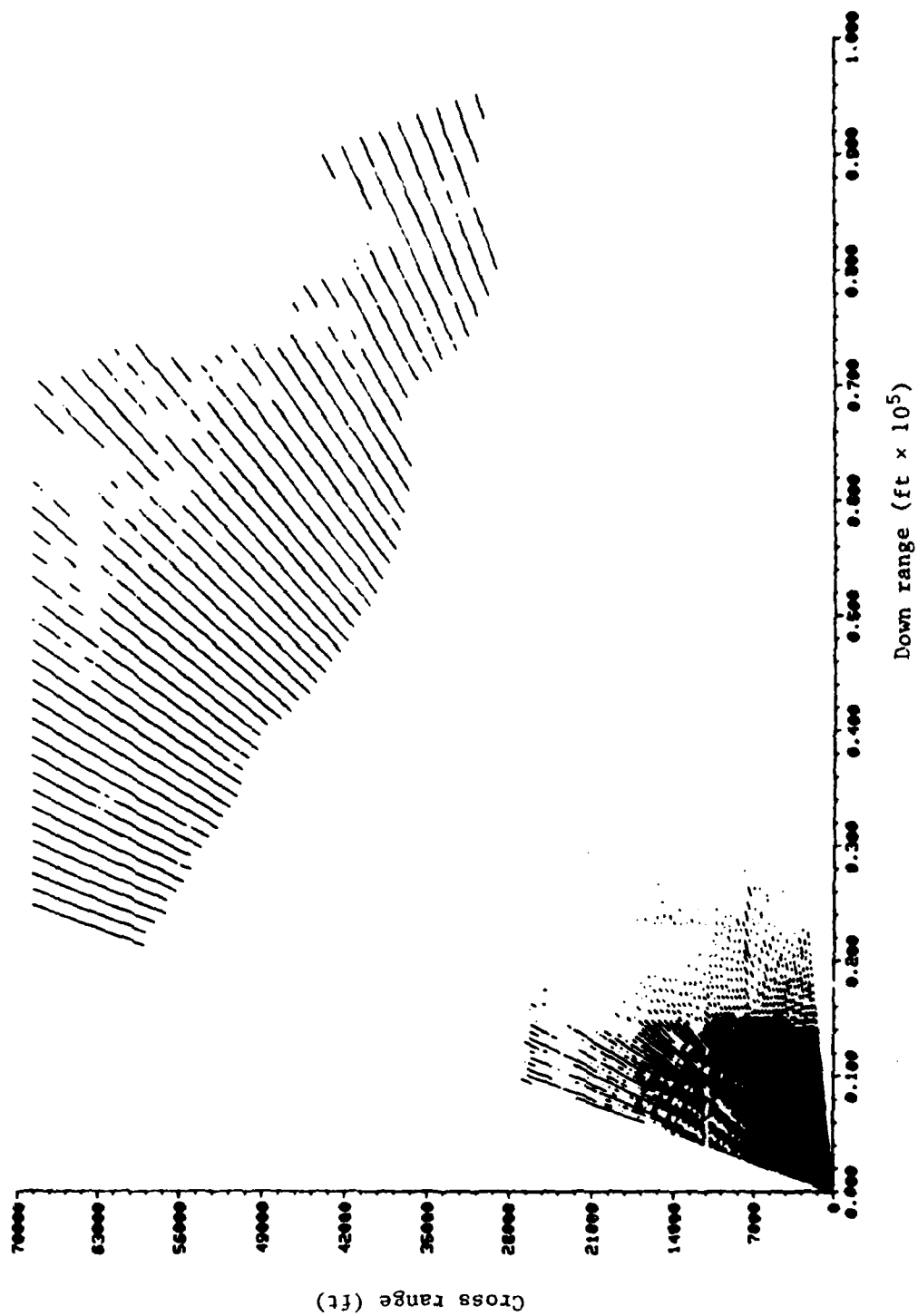


Figure 5. Illuminated region from EC 50, 34-foot radar height.

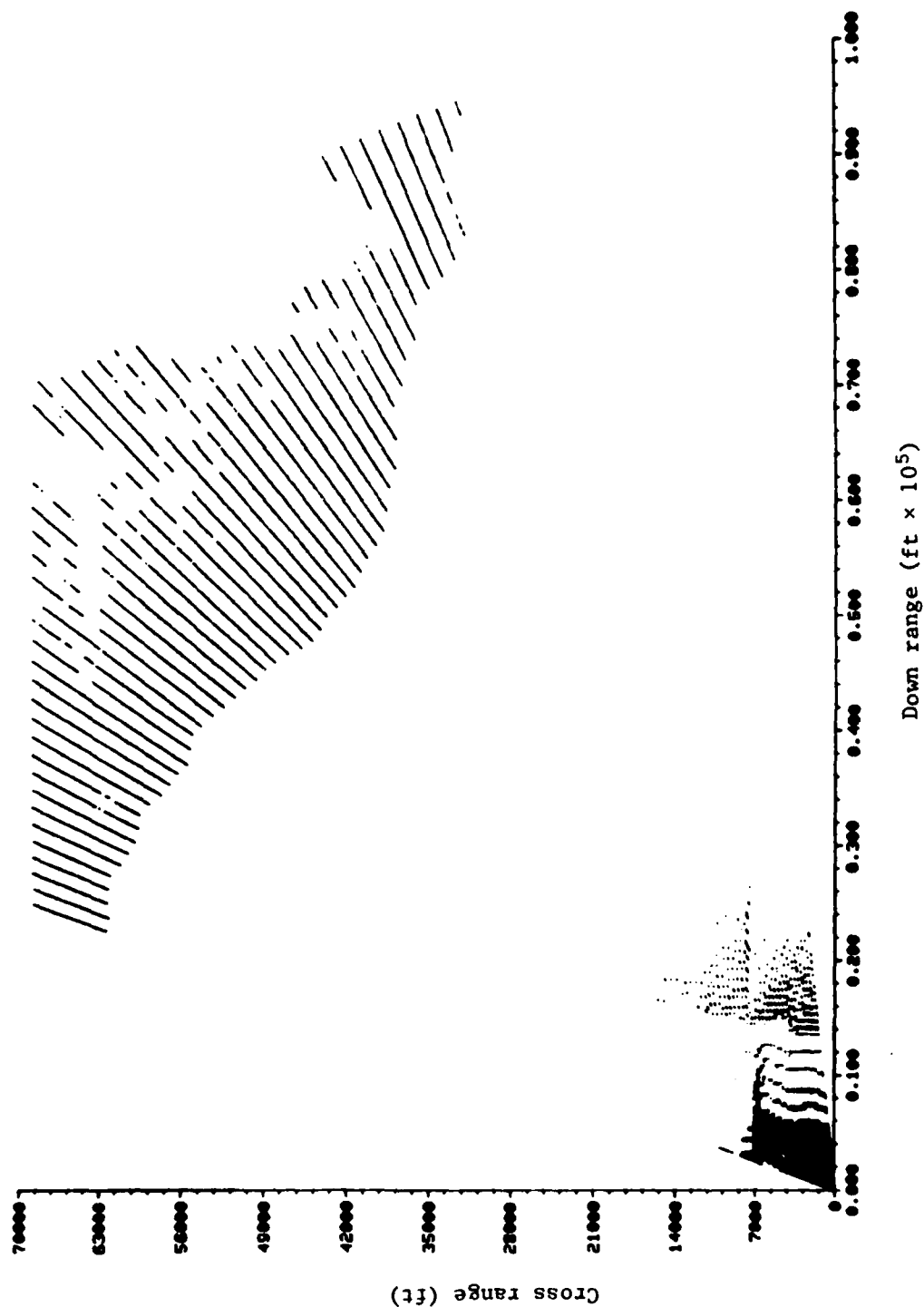


Figure 6. Illuminated region from EC 50, 9-foot radar height.



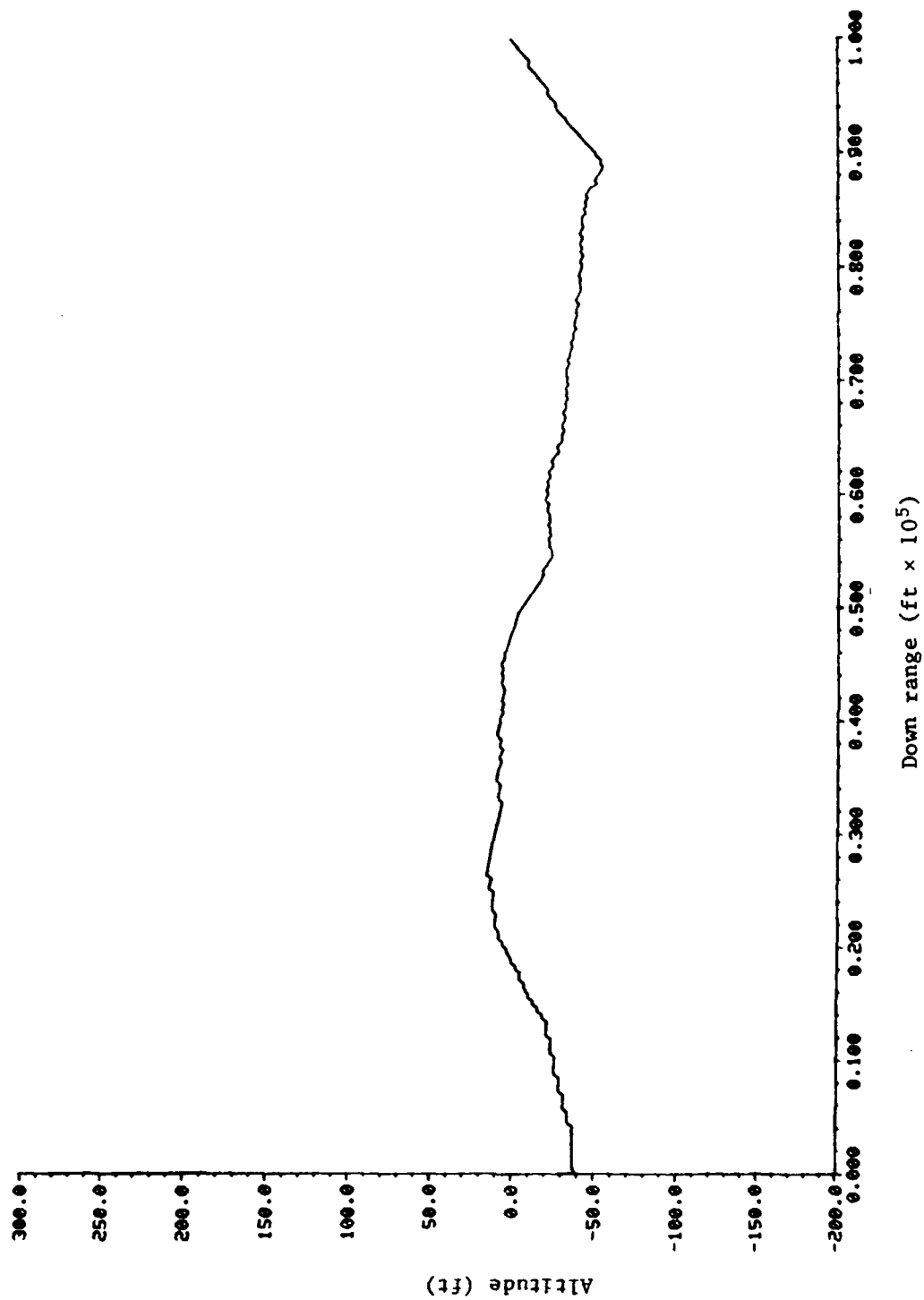


Figure 7. EC 50 elevation profile, -10° azimuth, 40-foot radar height.

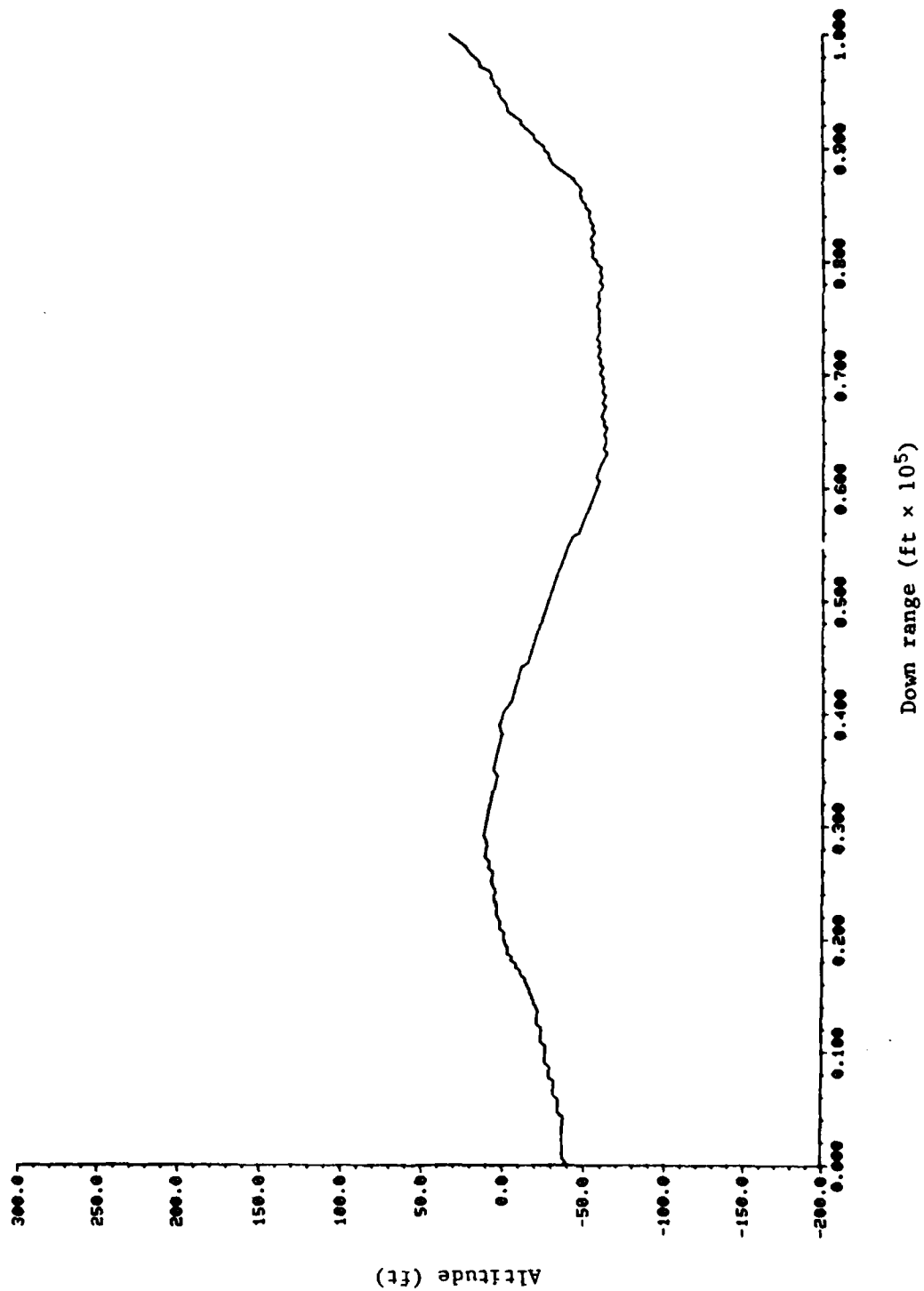


Figure 8. EC 50 elevation profile,  $-15^\circ$  azimuth, 40-foot radar height.

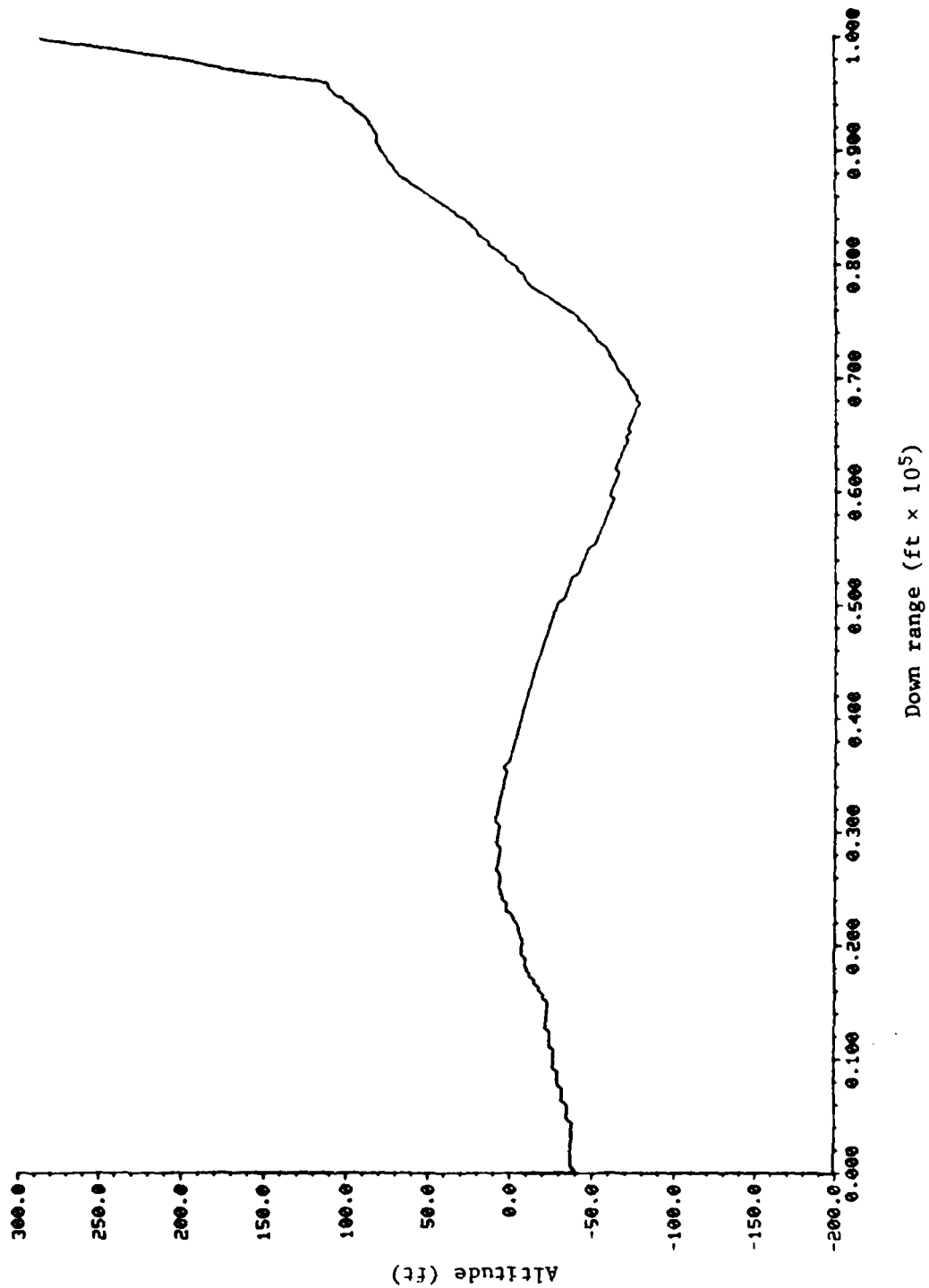


Figure 9. EC 50 elevation profile, -20° azimuth, 40-foot radar height.

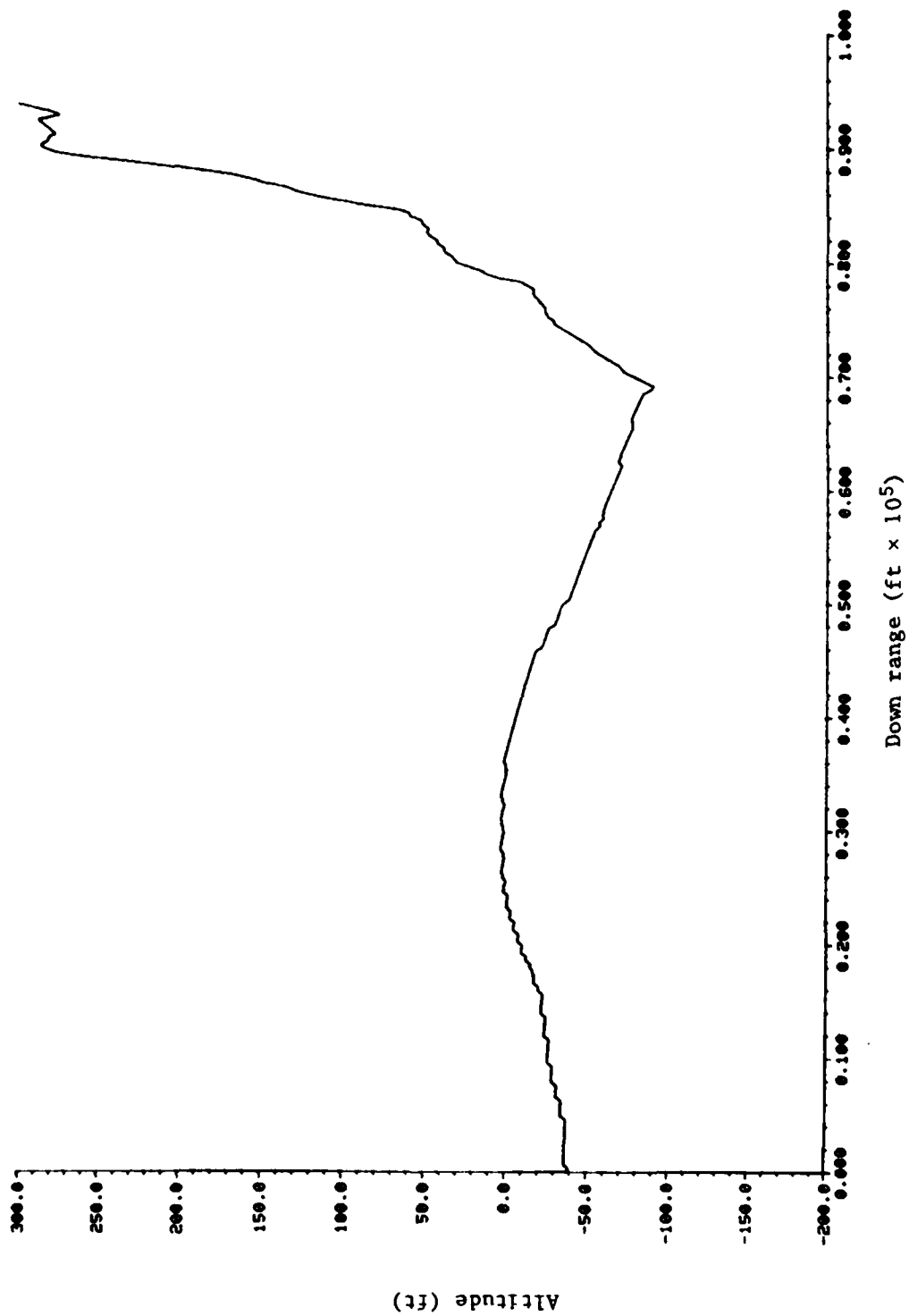


Figure 10. EC 50 elevation profile,  $-25^\circ$  azimuth, 40-foot radar height.

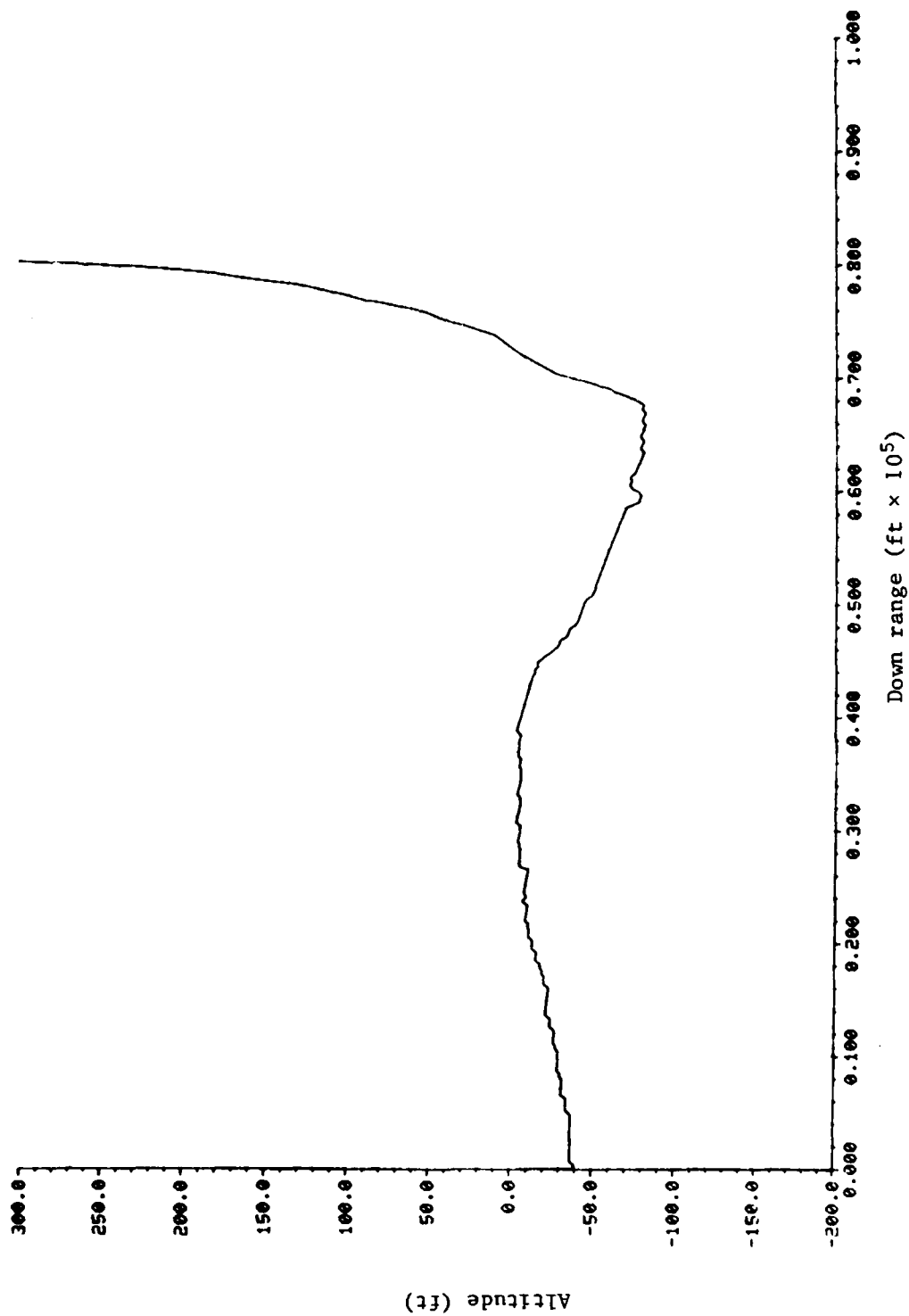


Figure 11. EC 50 elevation profile,  $-30^\circ$  azimuth, 40-foot radar height.

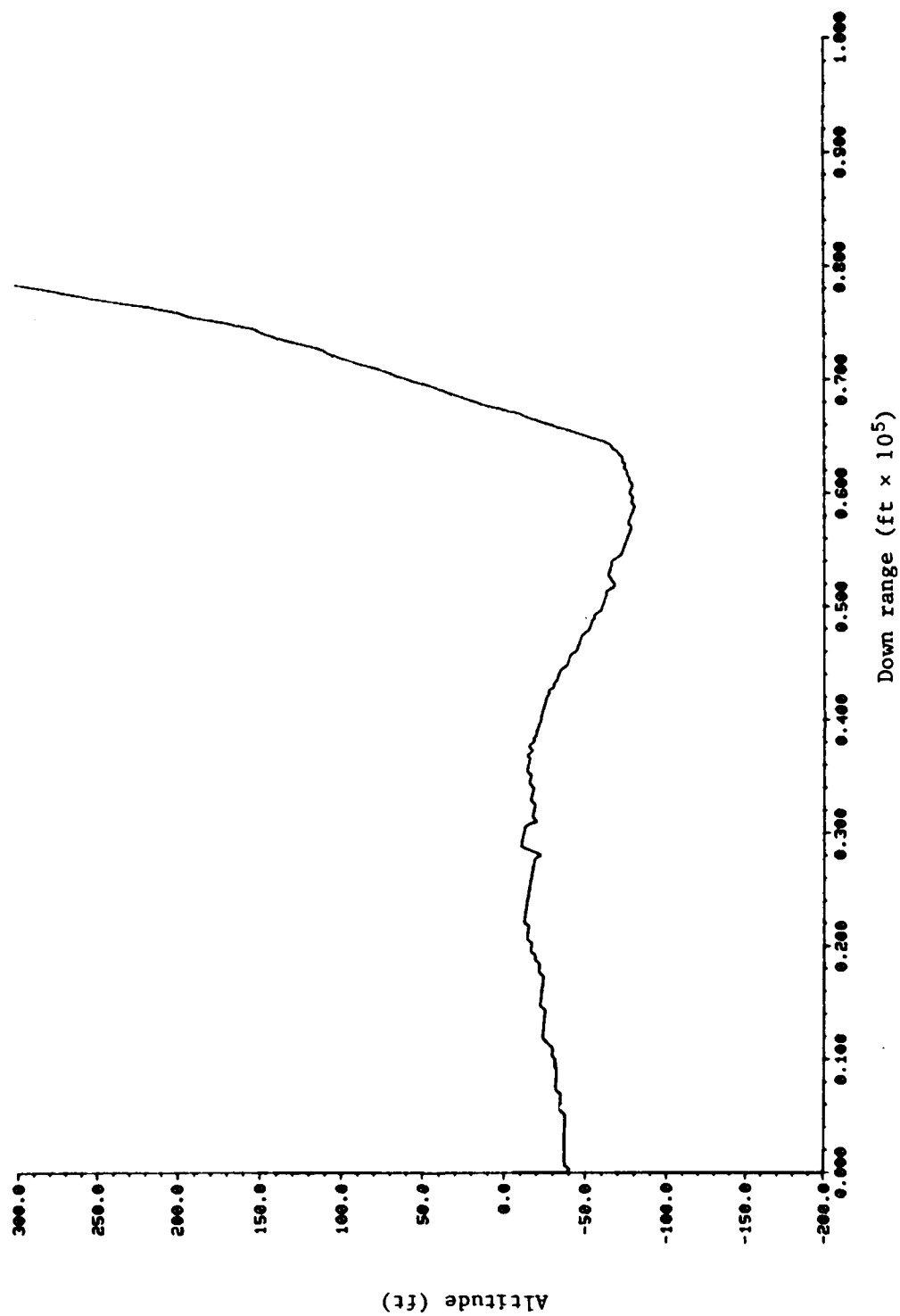


Figure 12. EC 50 elevation profile, -35° azimuth, 40-foot radar height.

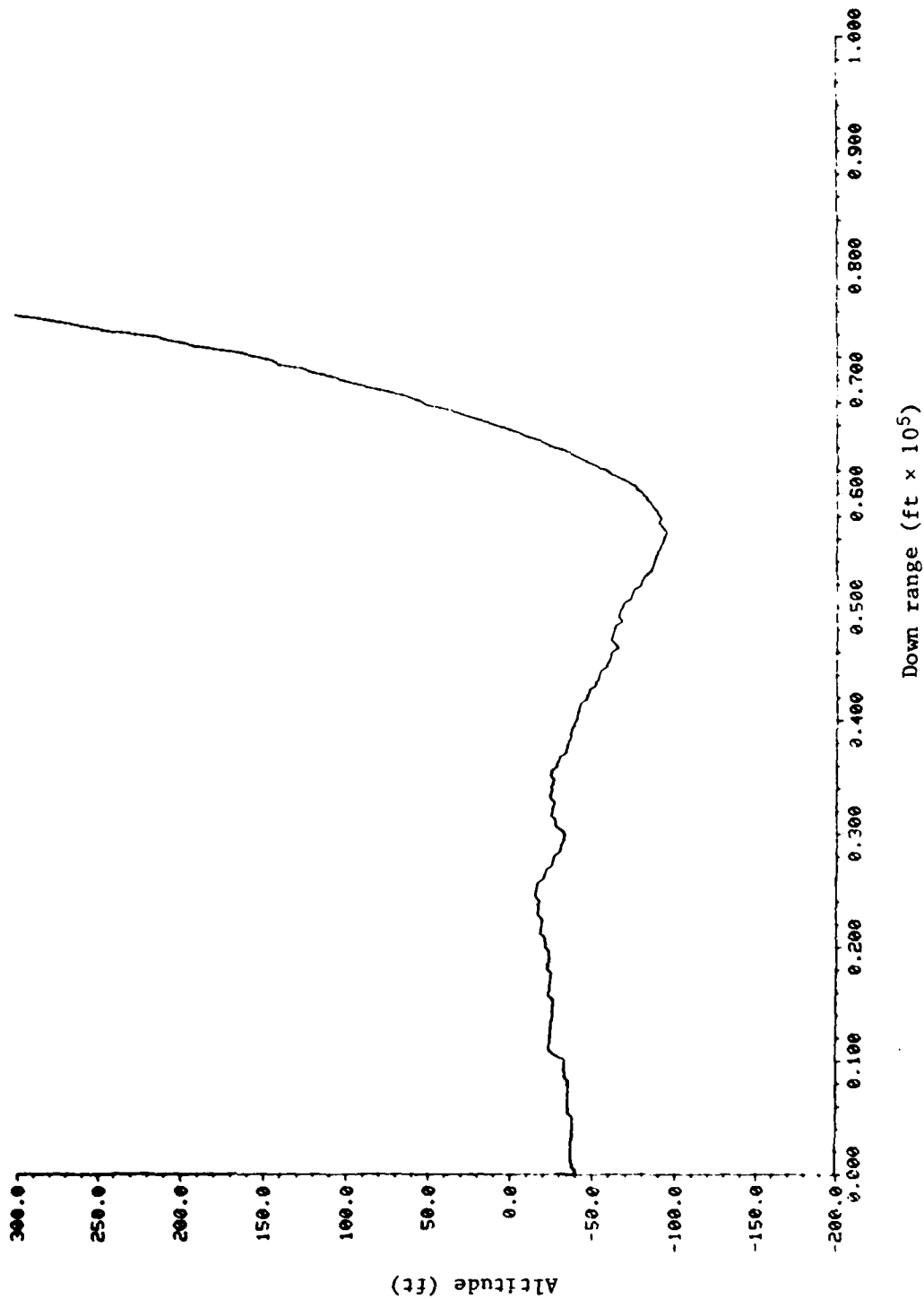


Figure 13. EC 50 elevation profile,  $-40^\circ$  azimuth, 40-foot radar height.

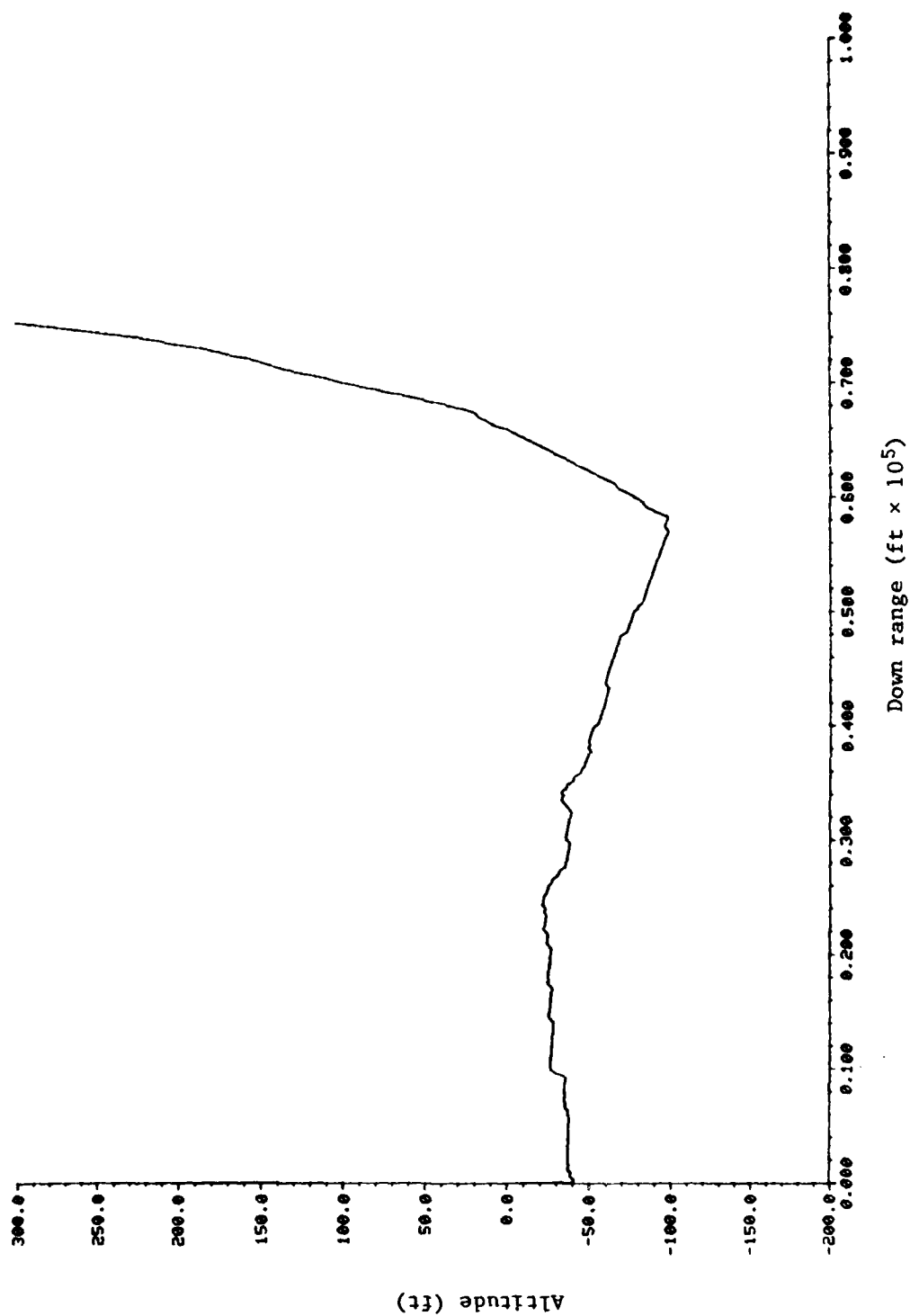


Figure 14. EC 50 elevation profile,  $-45^\circ$  azimuth, 40-foot radar height.



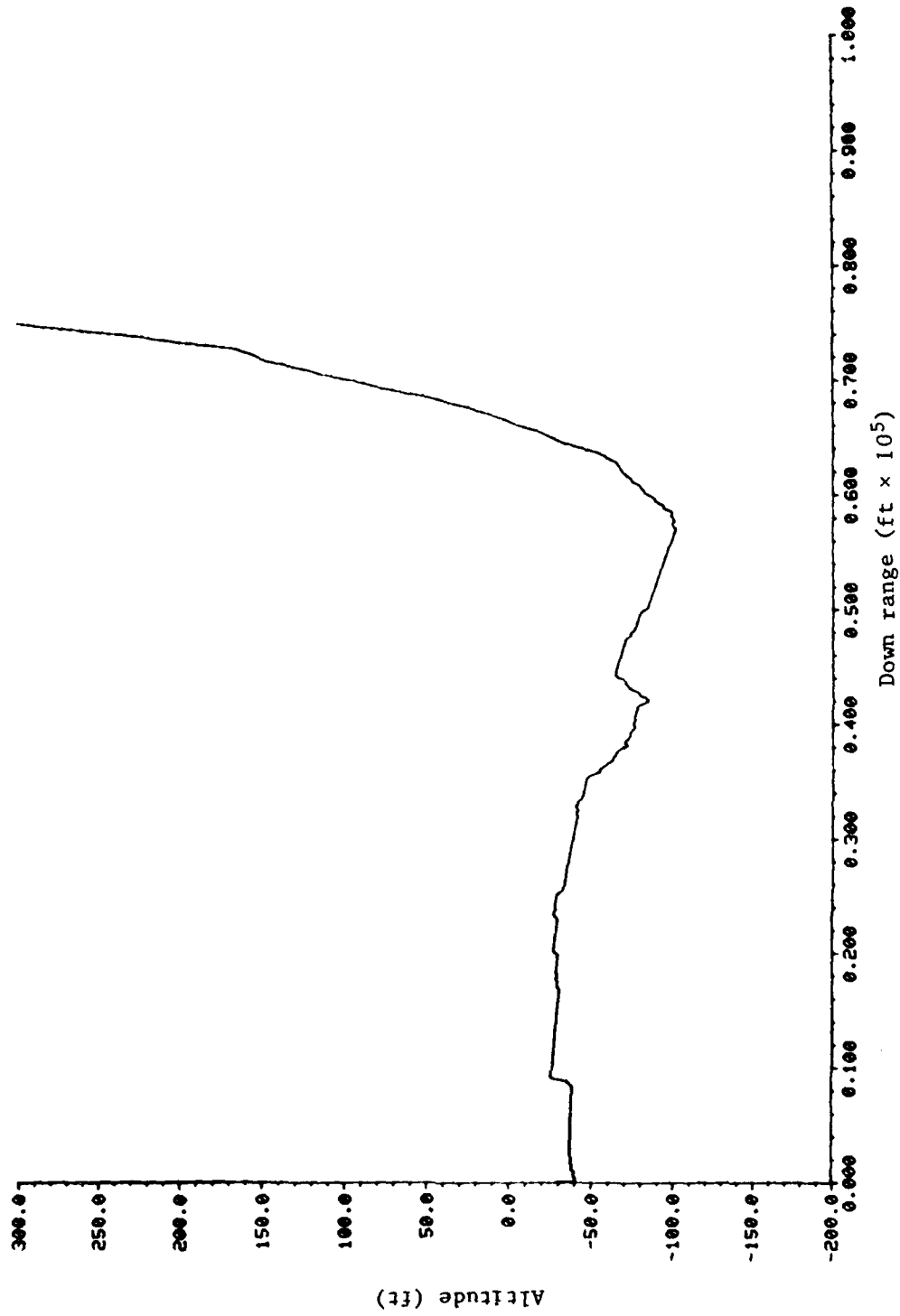


Figure 15. EC 50 elevation profile,  $-50^\circ$  azimuth, 40-foot radar height.

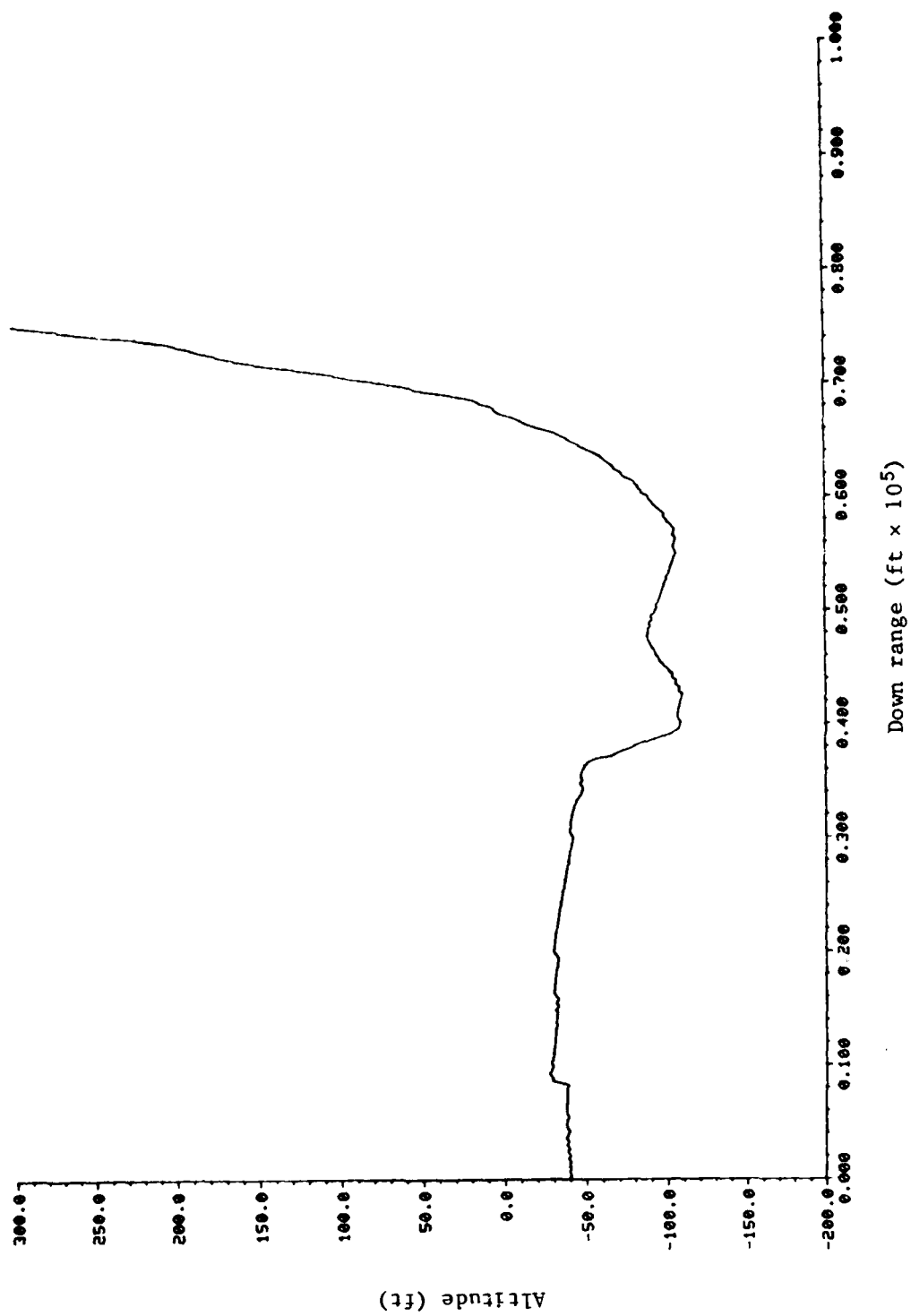


Figure 16. EC 50 elevation profile, -55° azimuth, 40-foot radar height.

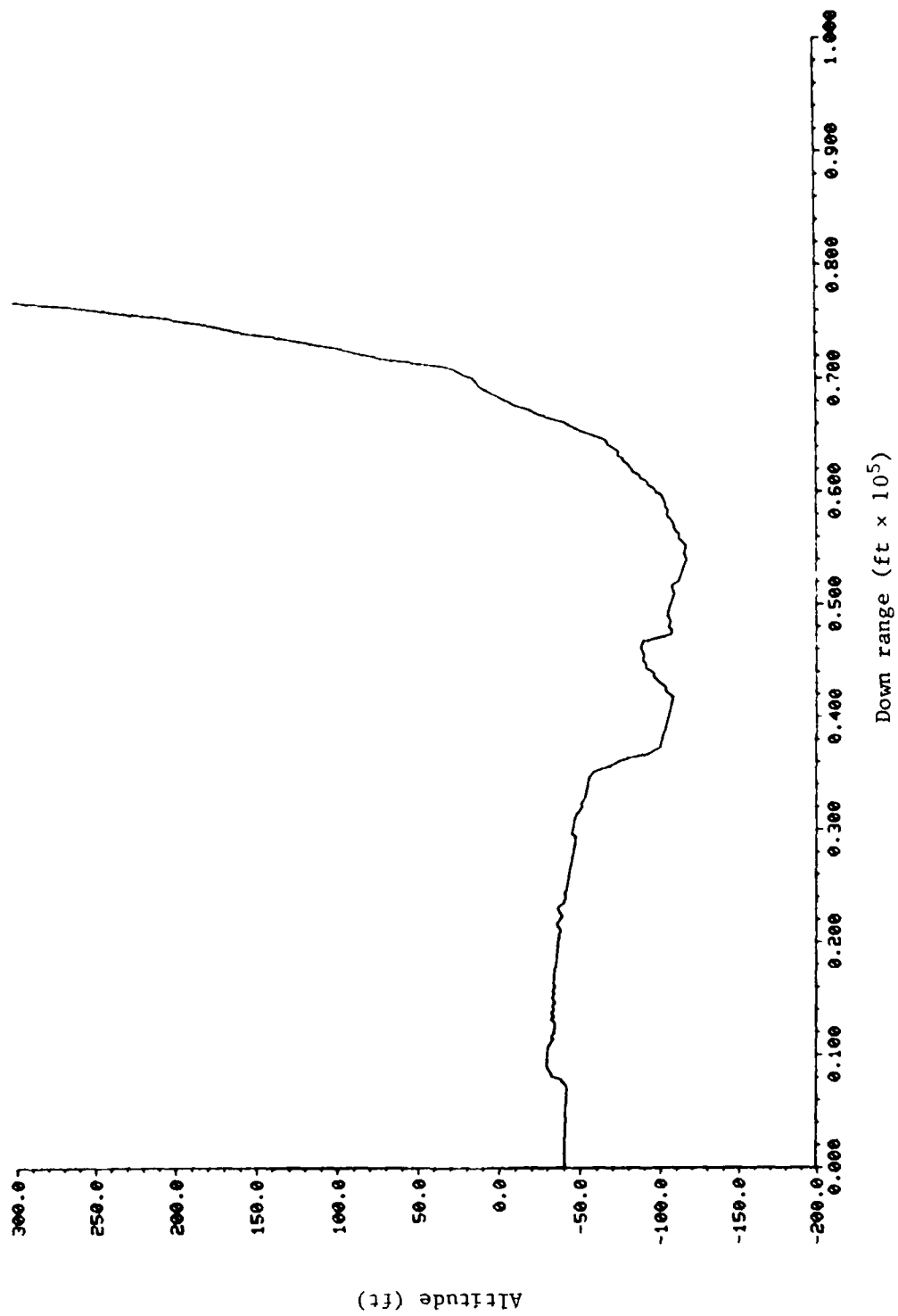


Figure 17. EC 50 elevation profile,  $-60^\circ$  azimuth, 40-foot radar height.

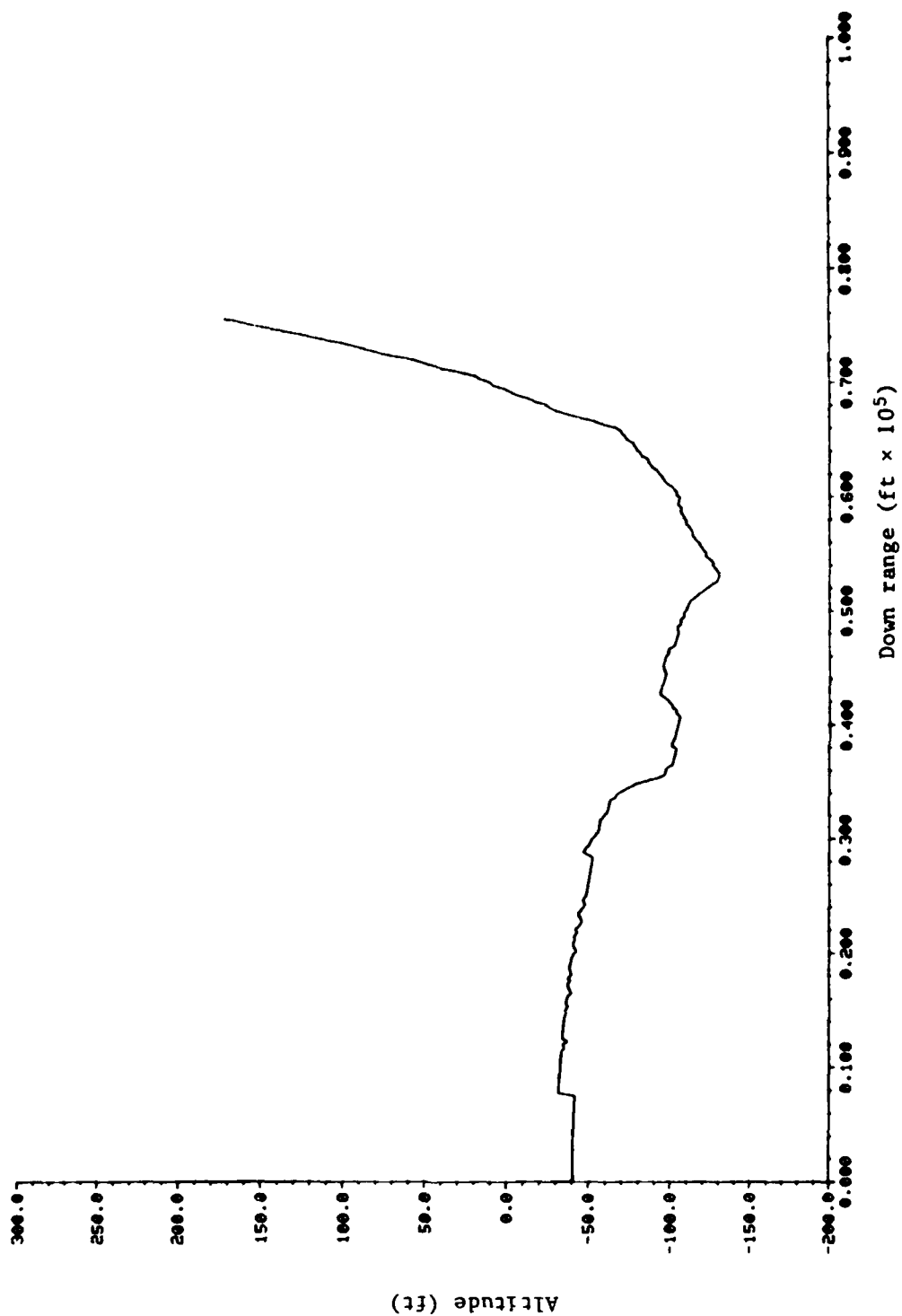


Figure 18. EC 50 elevation profile, -65° azimuth, 40-foot radar height.

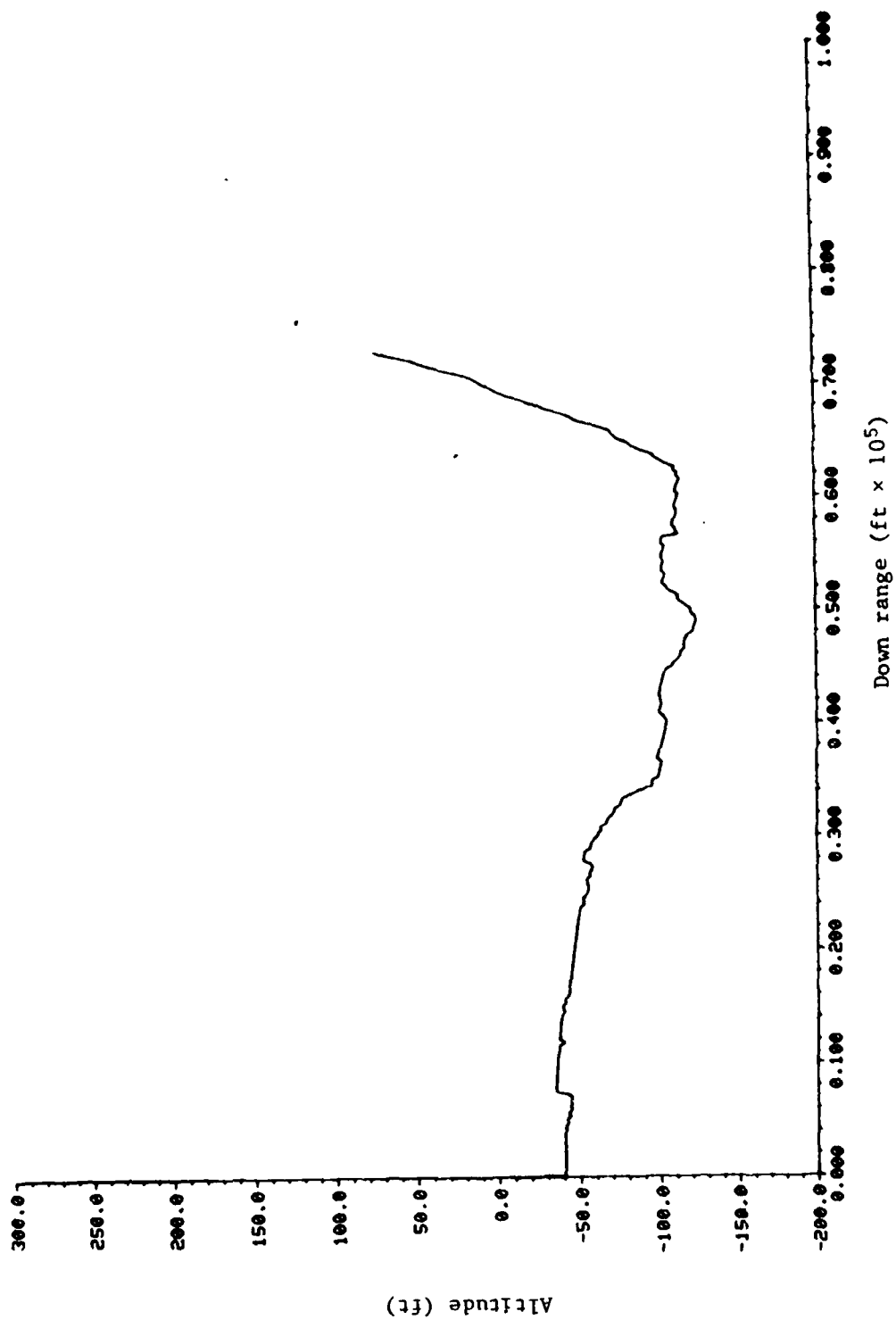


Figure 19. EC 50 elevation profile,  $-70^\circ$  azimuth, 40-foot radar height.

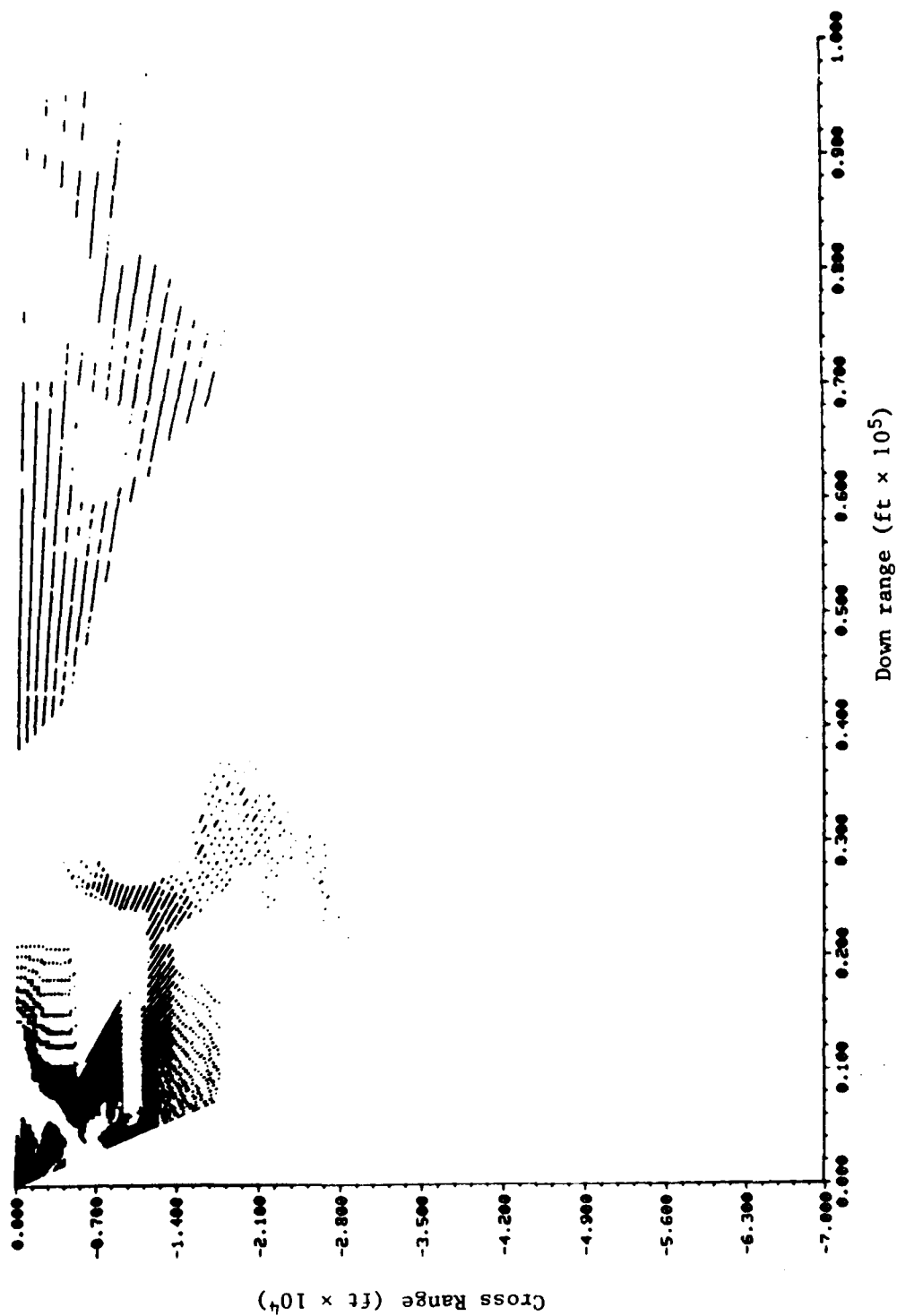


Figure 20. Illuminated region from WC 50, 9-foot radar height.

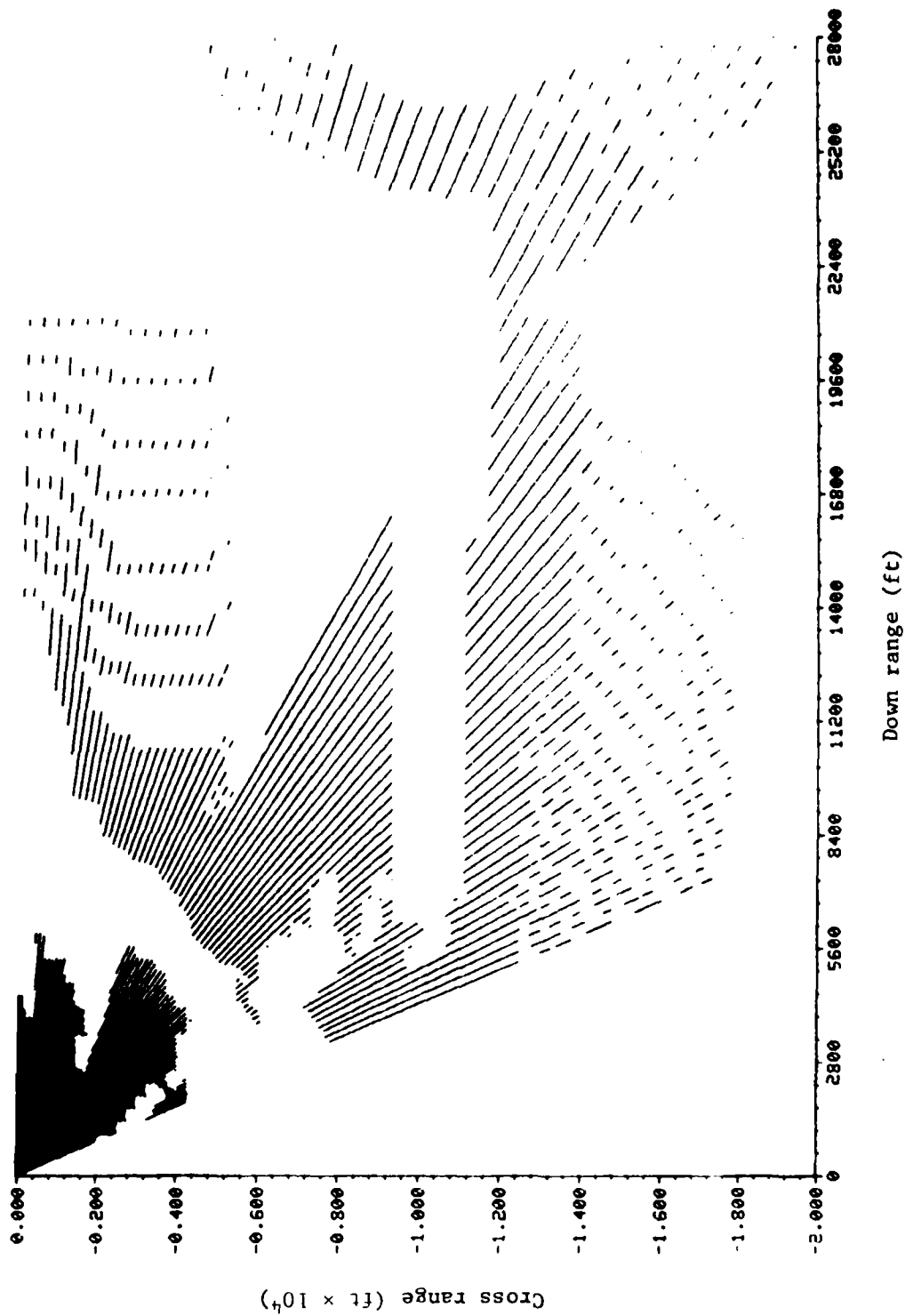


Figure 21. Illuminated region from WC 50, expanded scale, 9-foot radar height.

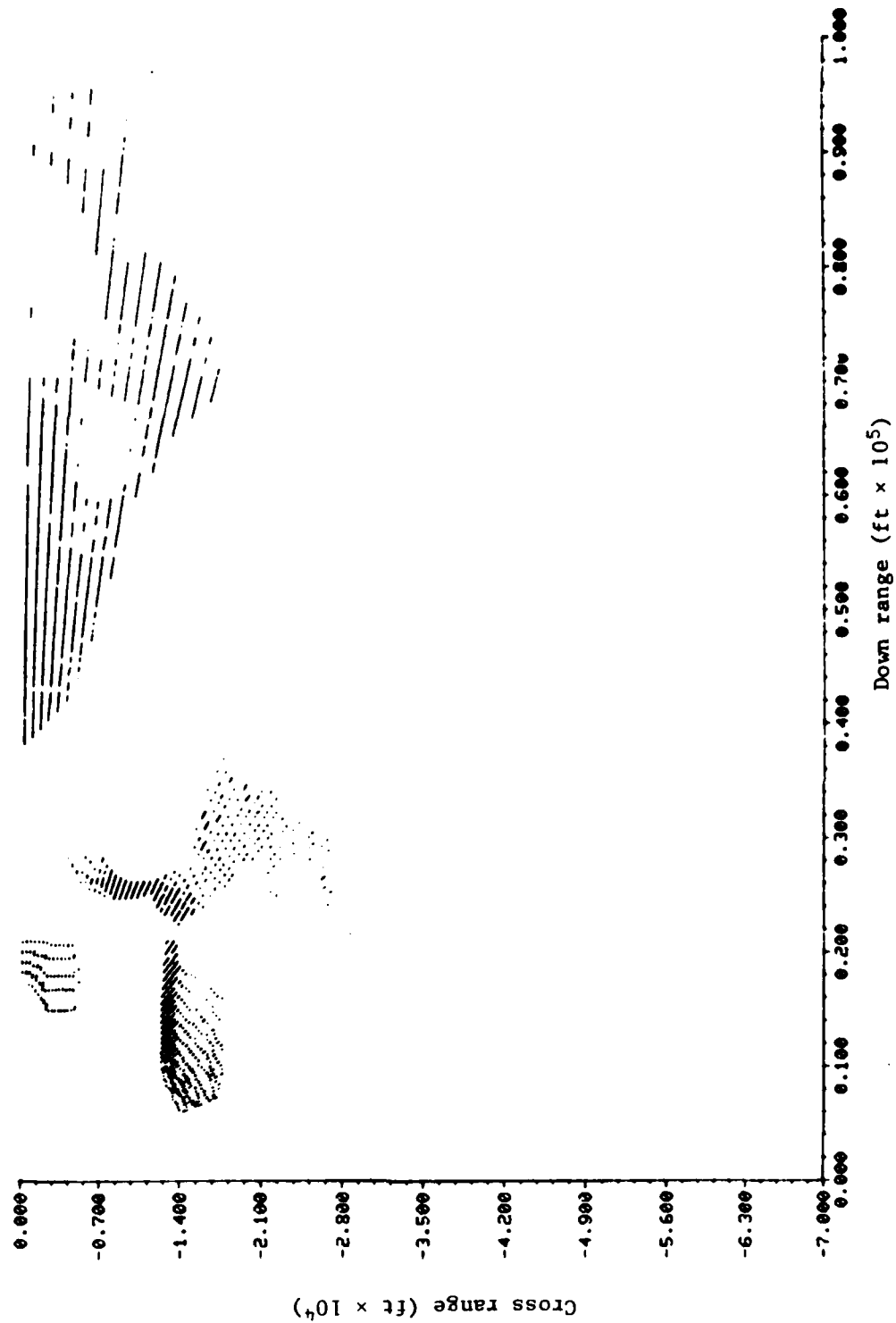


Figure 22. Illuminated region from WC 50, 9-foot radar height, 9-foot fence height at a 100-foot range.



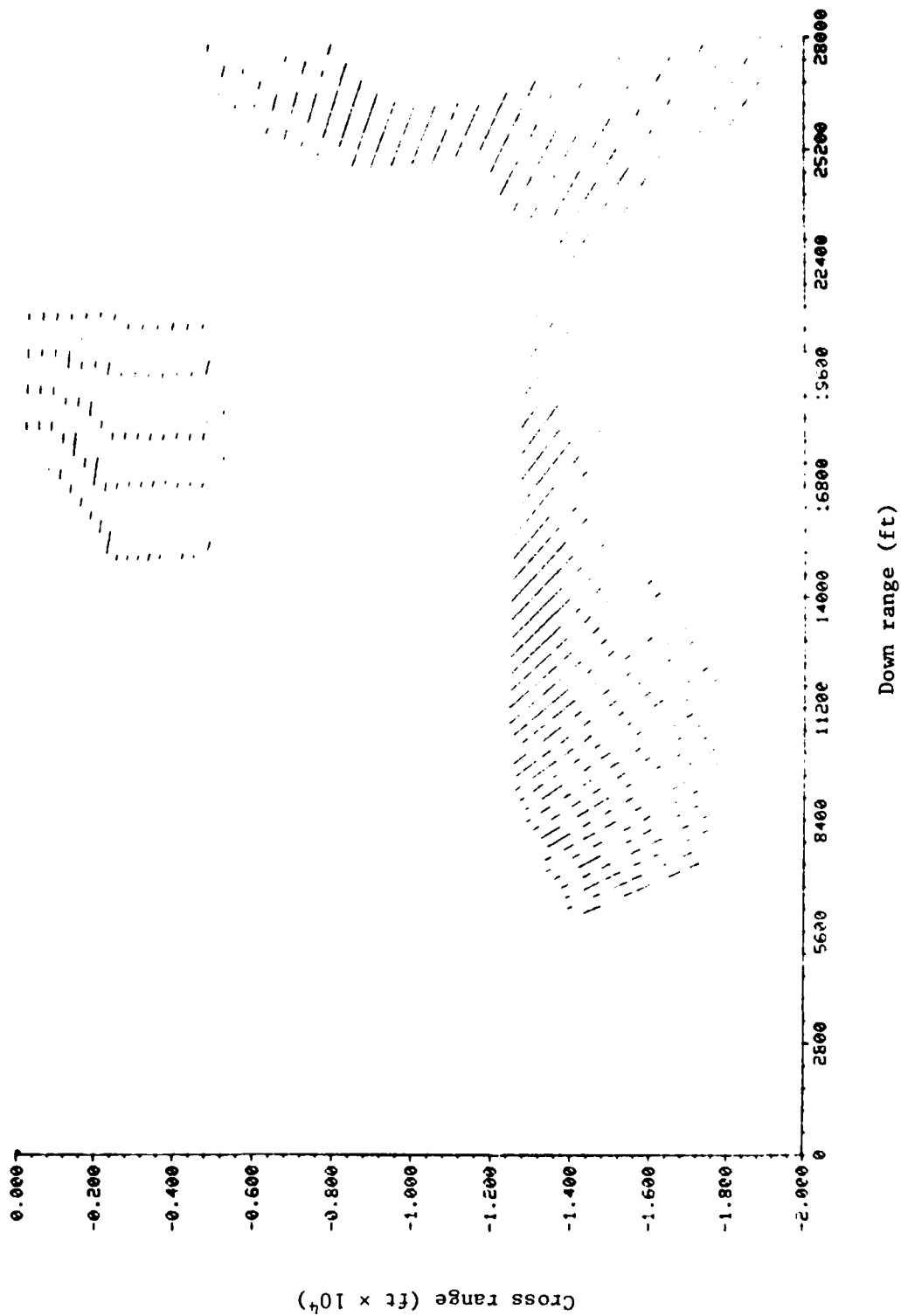


Figure 23. Illuminated region from WC 50, expanded scale, 9-foot radar height, 9-foot fence height at a 100-foot range.

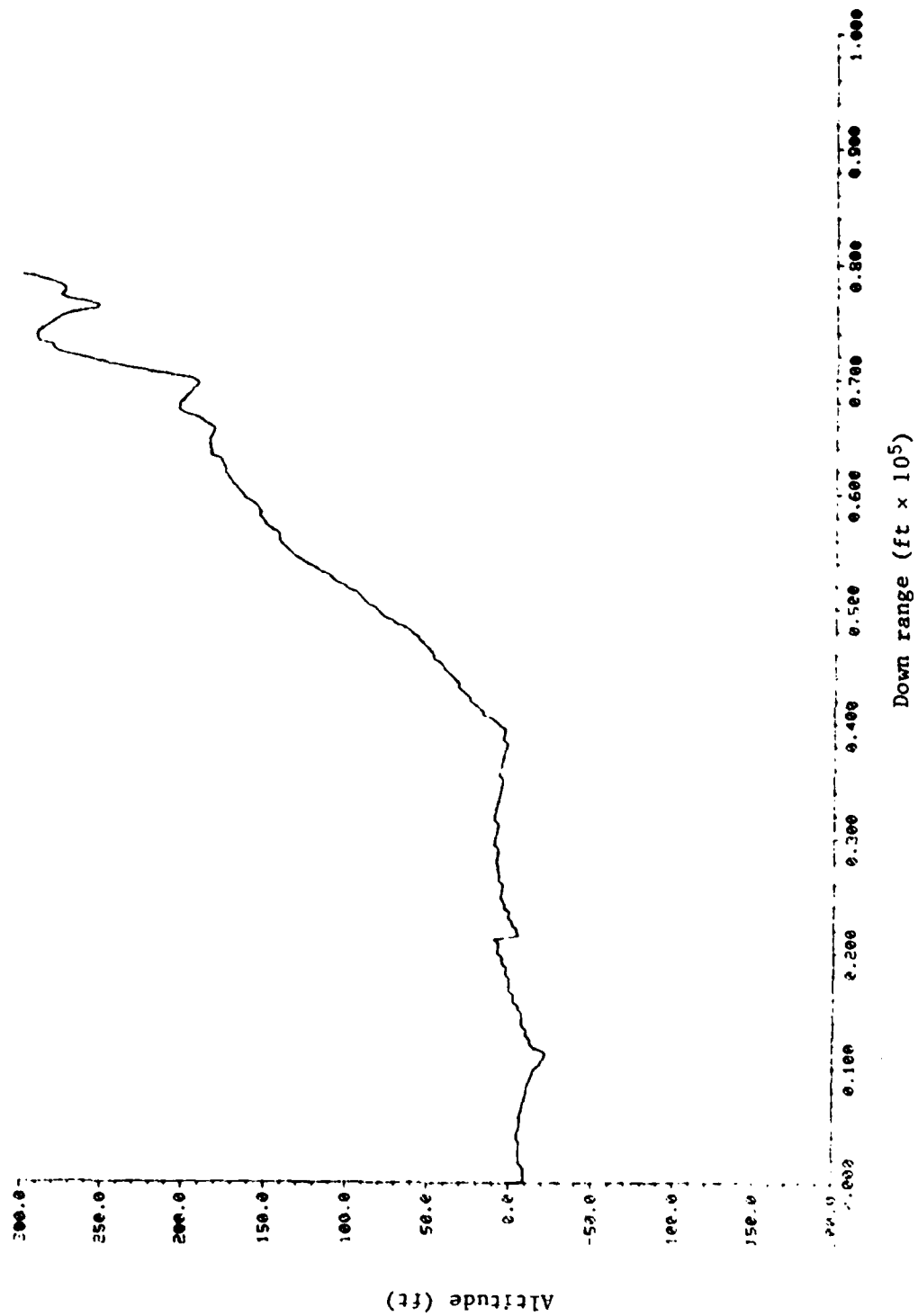


Figure 24. WC 50 elevation profile, 5° azimuth, 9-foot radar height.

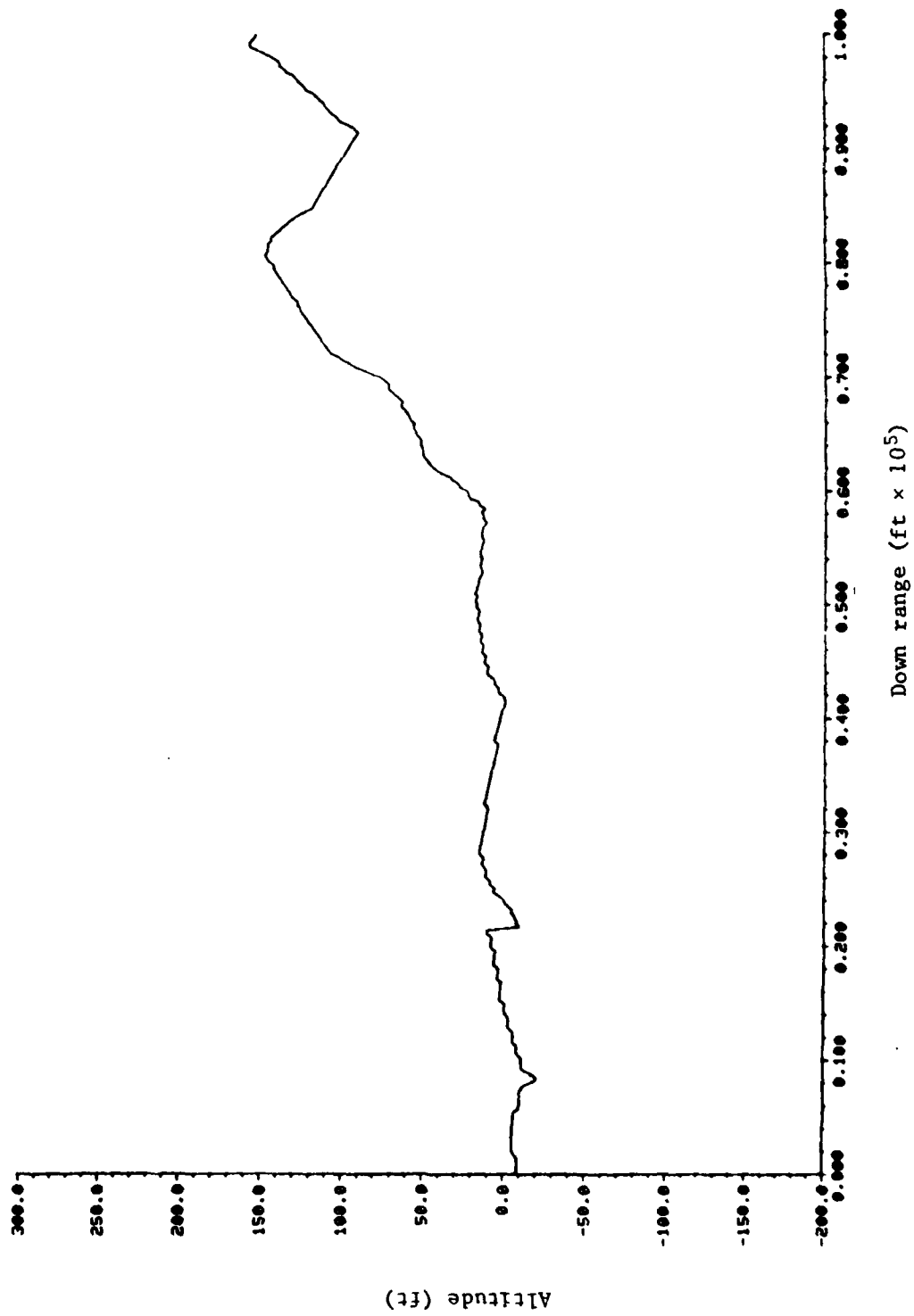


Figure 25. WC 50 elevation profile, 10° azimuth, 9-foot radar height.

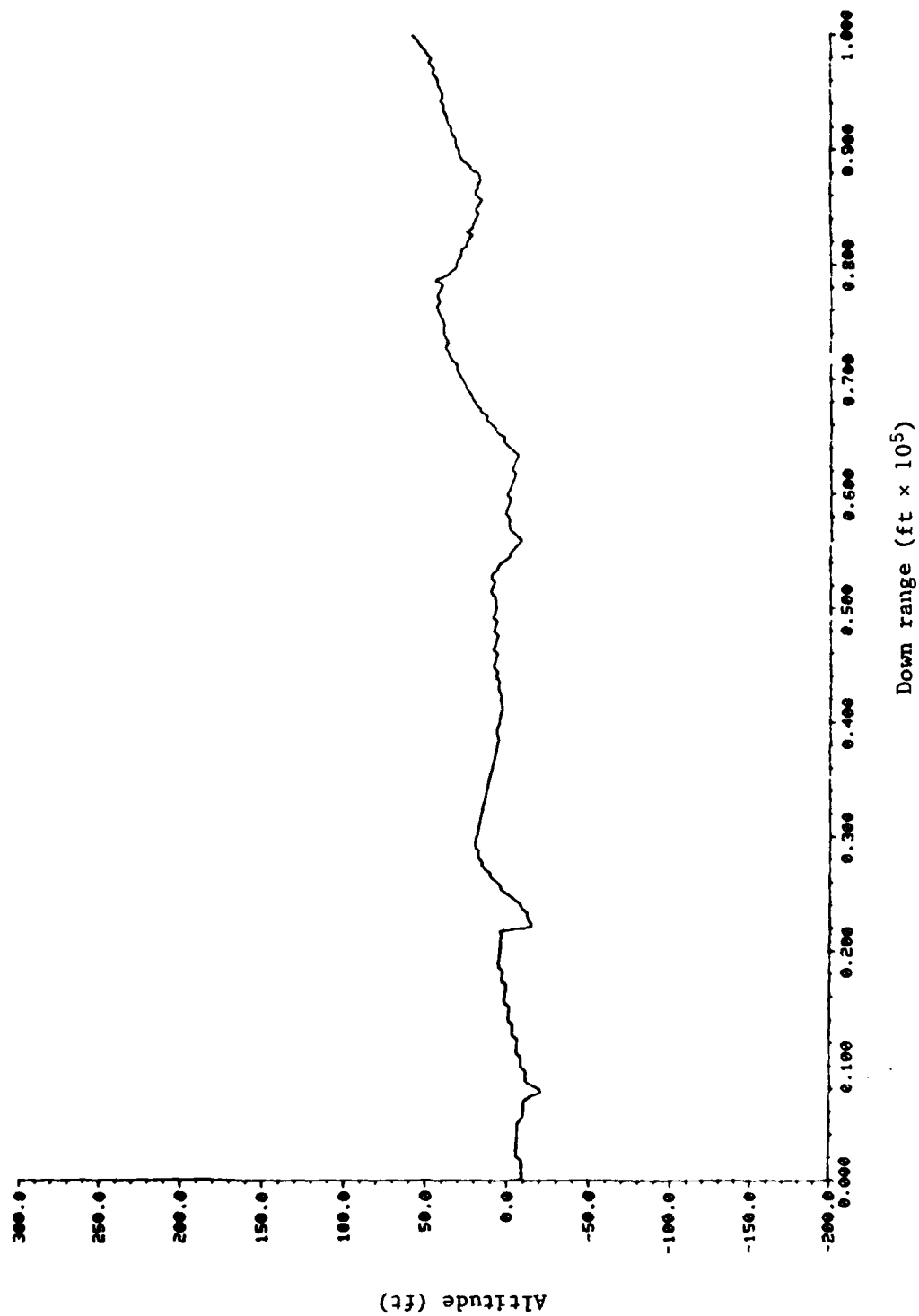


Figure 26. WC 50 elevation profile, 15° azimuth, 9-foot radar height.

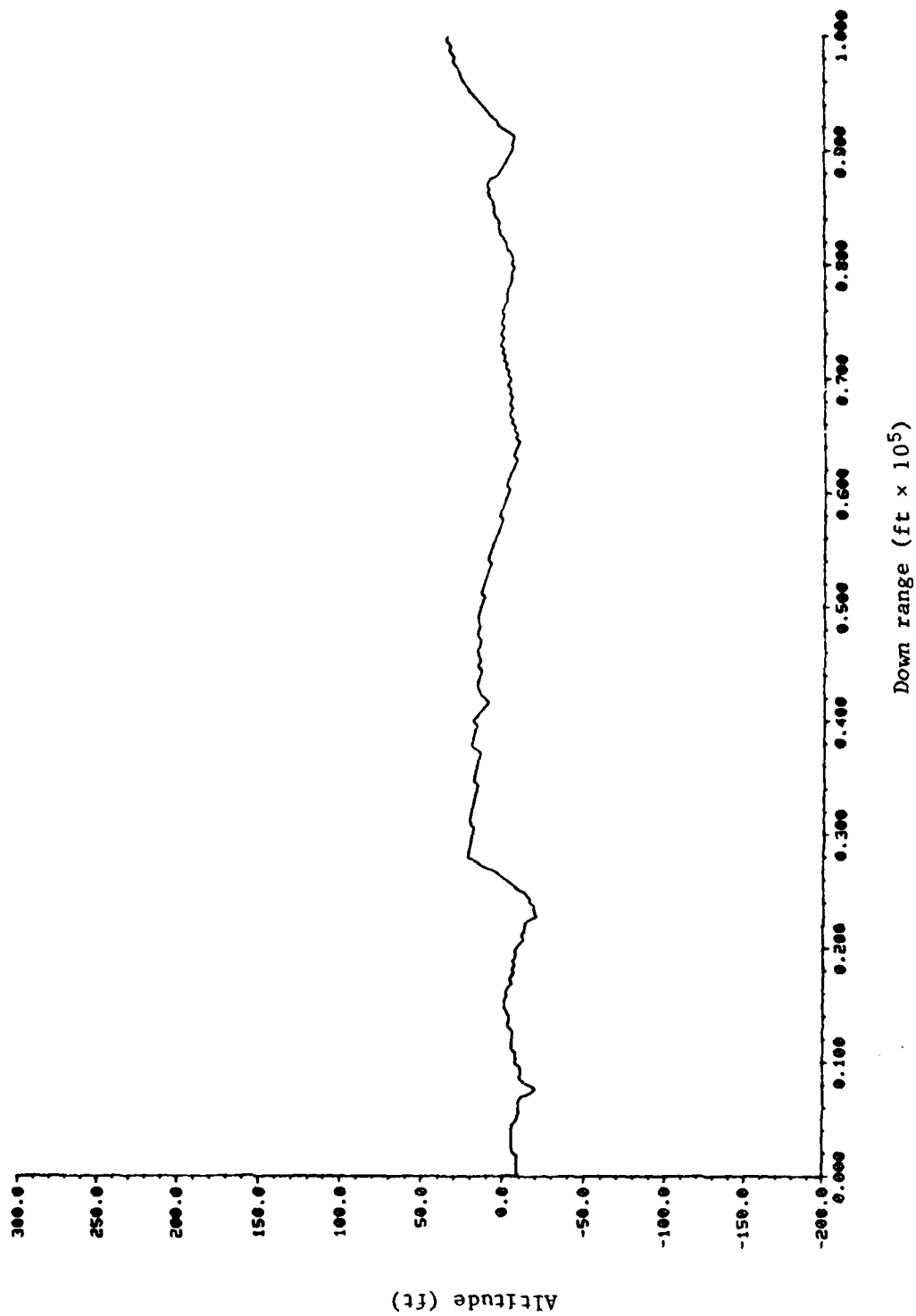


Figure 27. WC 50 elevation profile, 20° azimuth, 9-foot radar height.

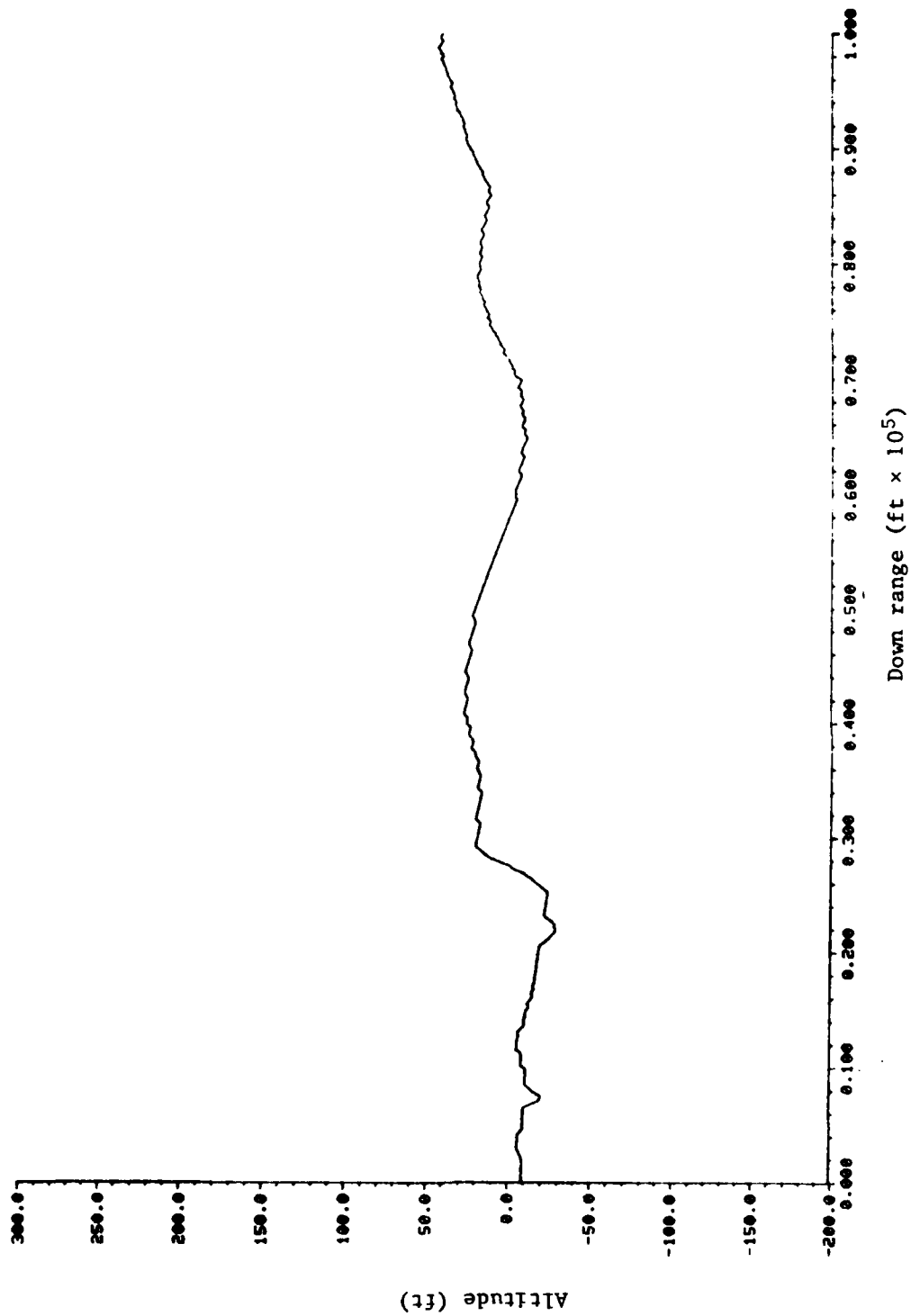


Figure 28. WC 50 elevation profile, 25° azimuth, 9-foot radar height.

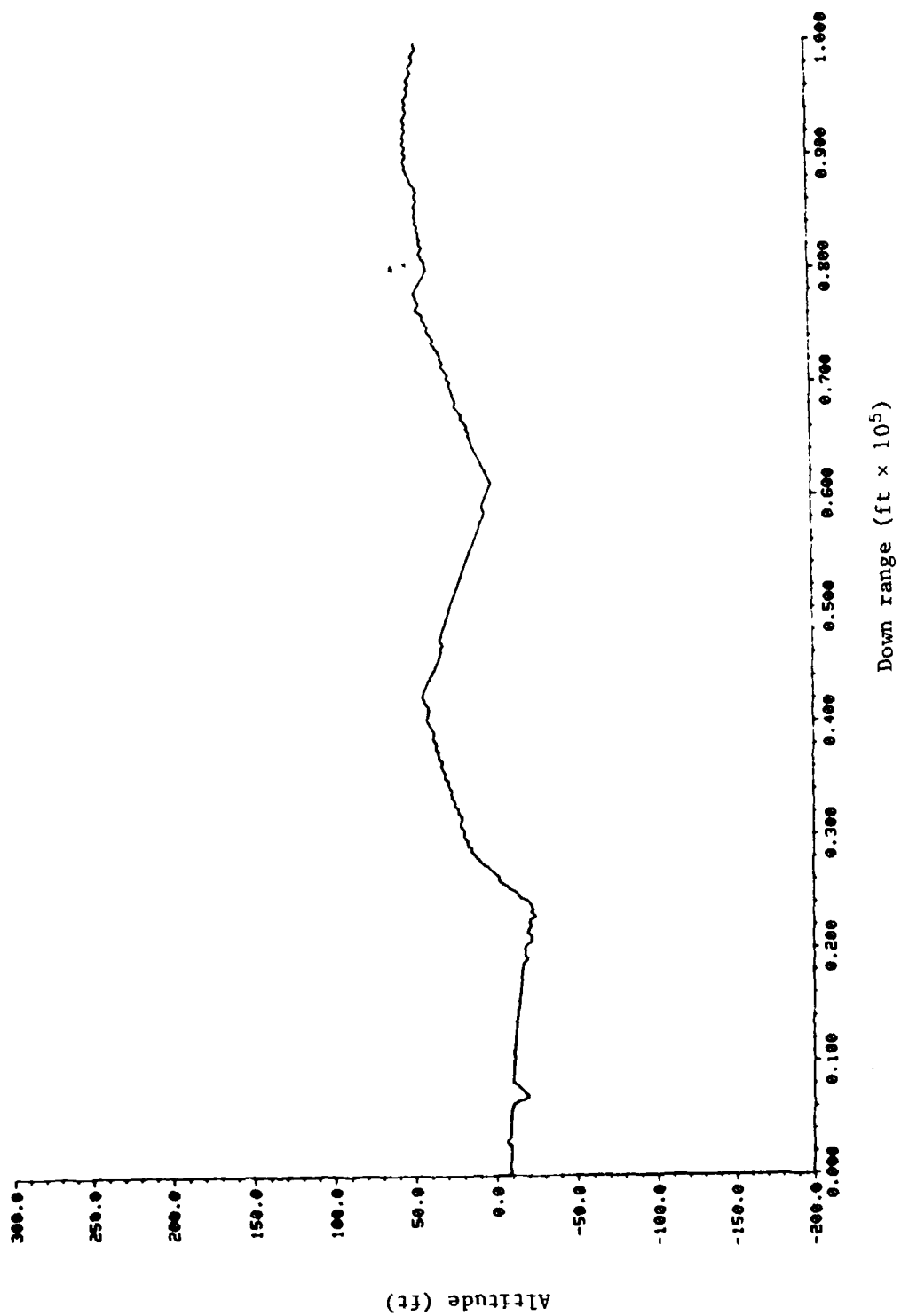


Figure 29. WC 50 elevation profile, 30° azimuth, 9-foot radar height.

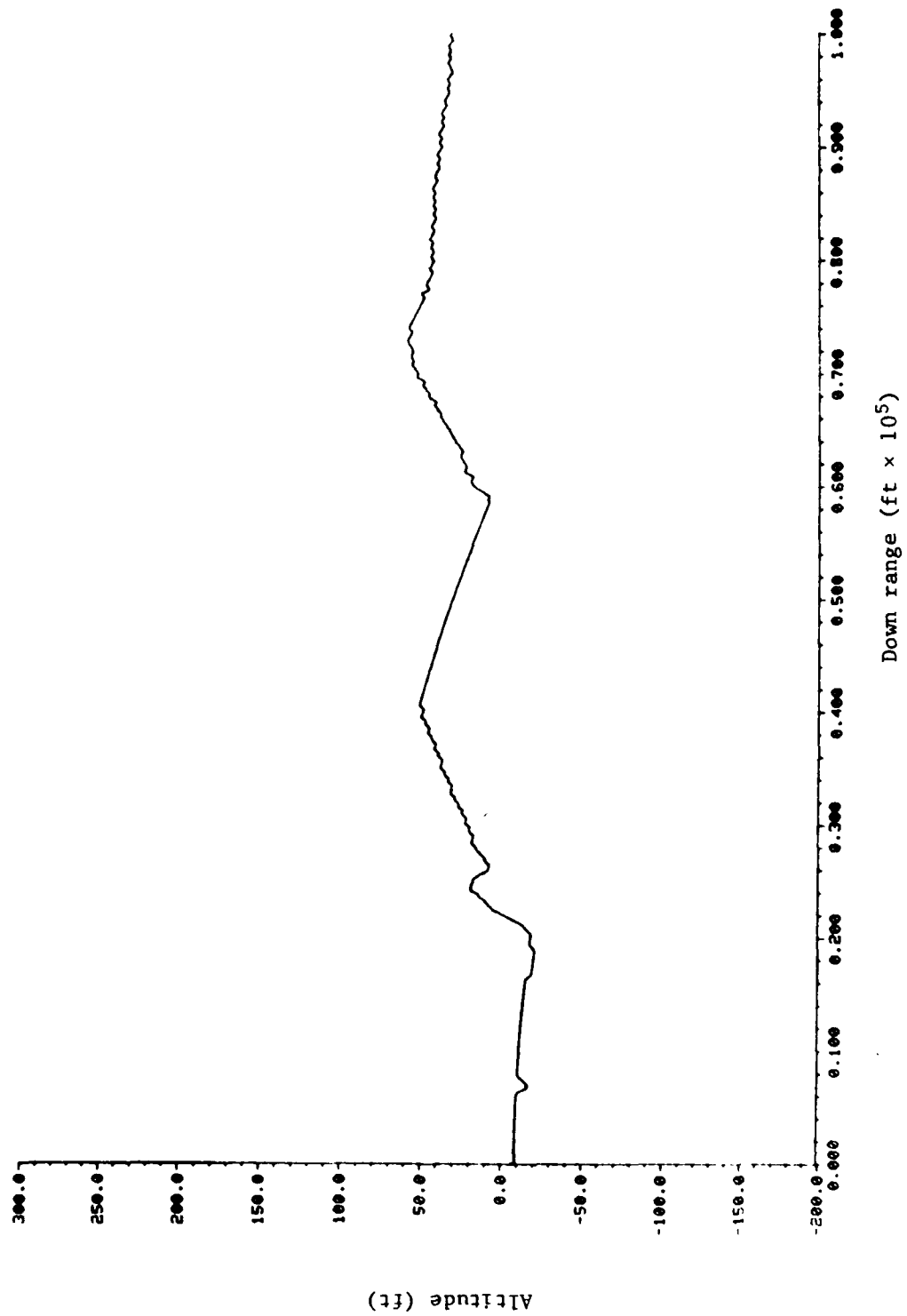


Figure 30. WC 50 elevation profile, 35° azimuth, 9-foot radar height.



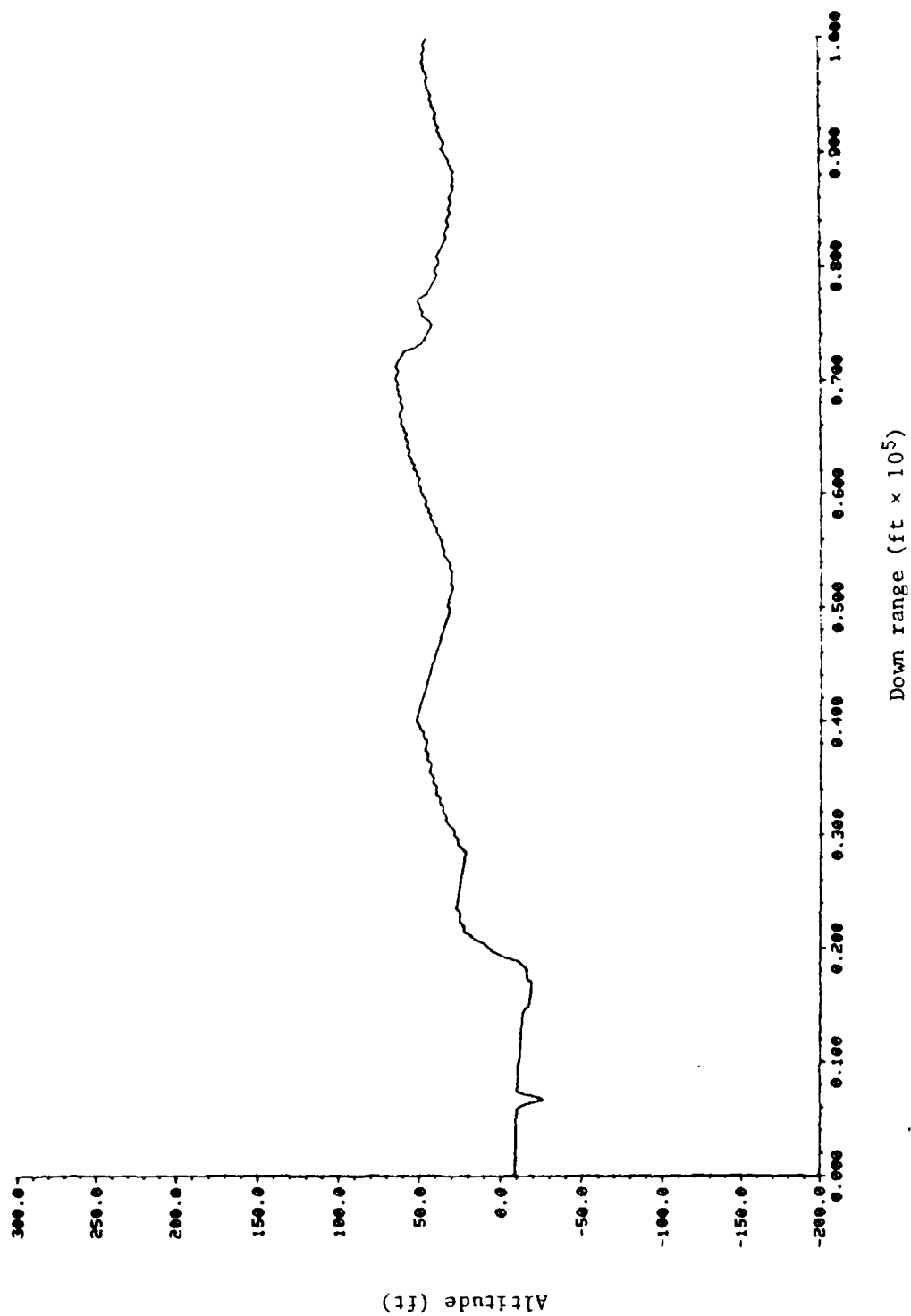


Figure 31. WC 50 elevation profile, 40° azimuth, 9-foot radar height.

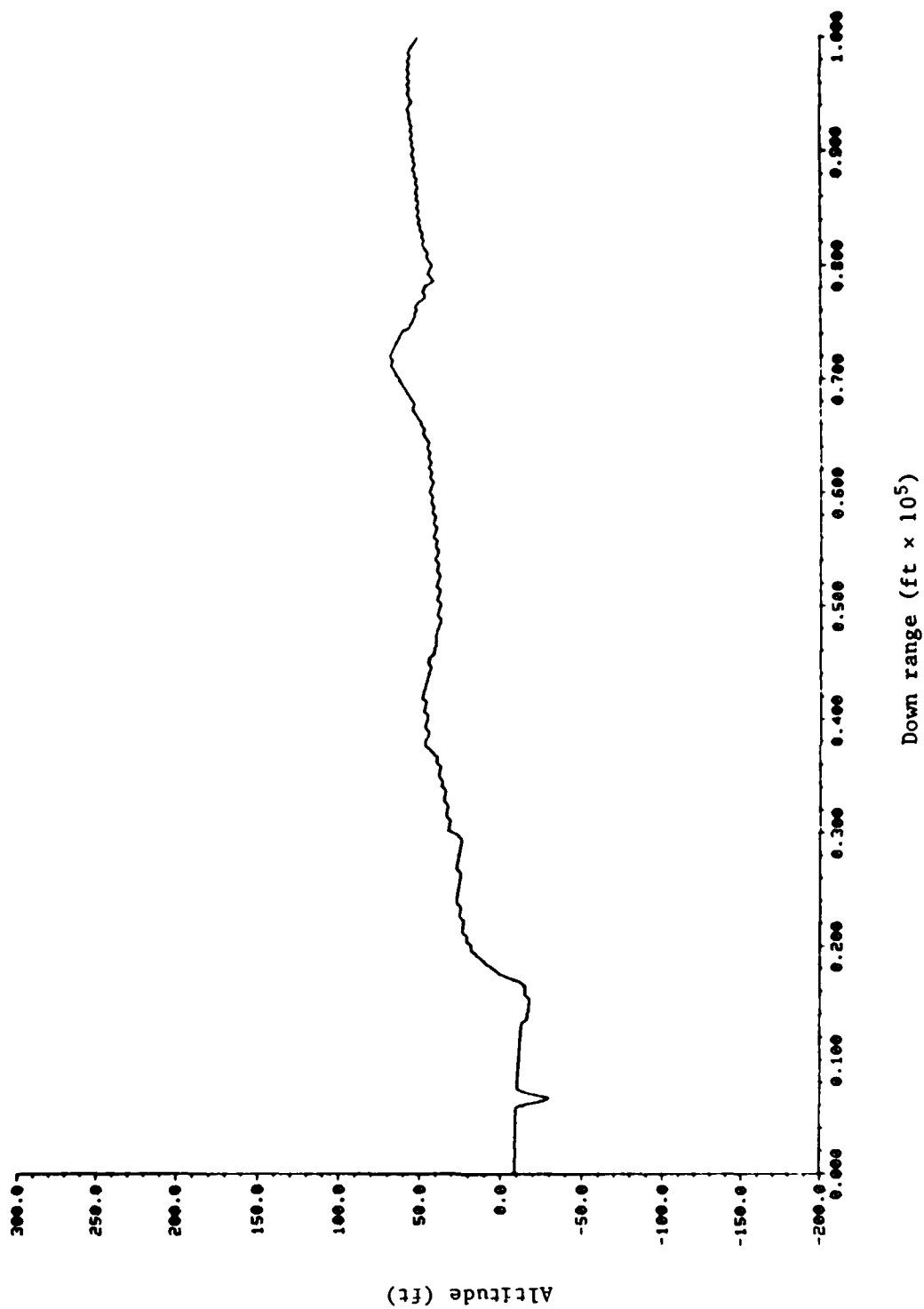


Figure 32. WC 50 elevation profile, 45° azimuth, 9-foot radar height.

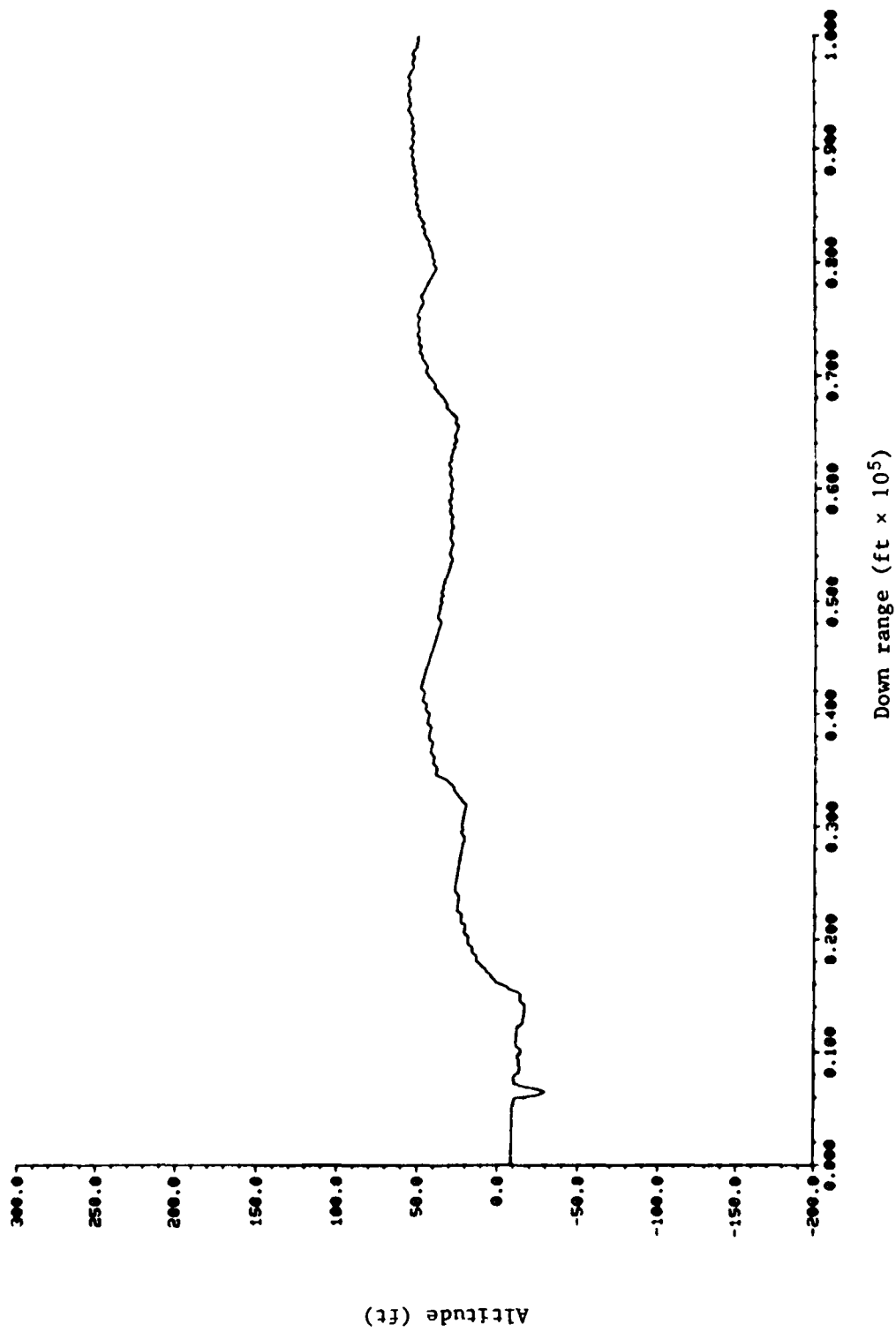


Figure 33. WC 50 elevation profile, 50° azimuth, 9-foot radar height.

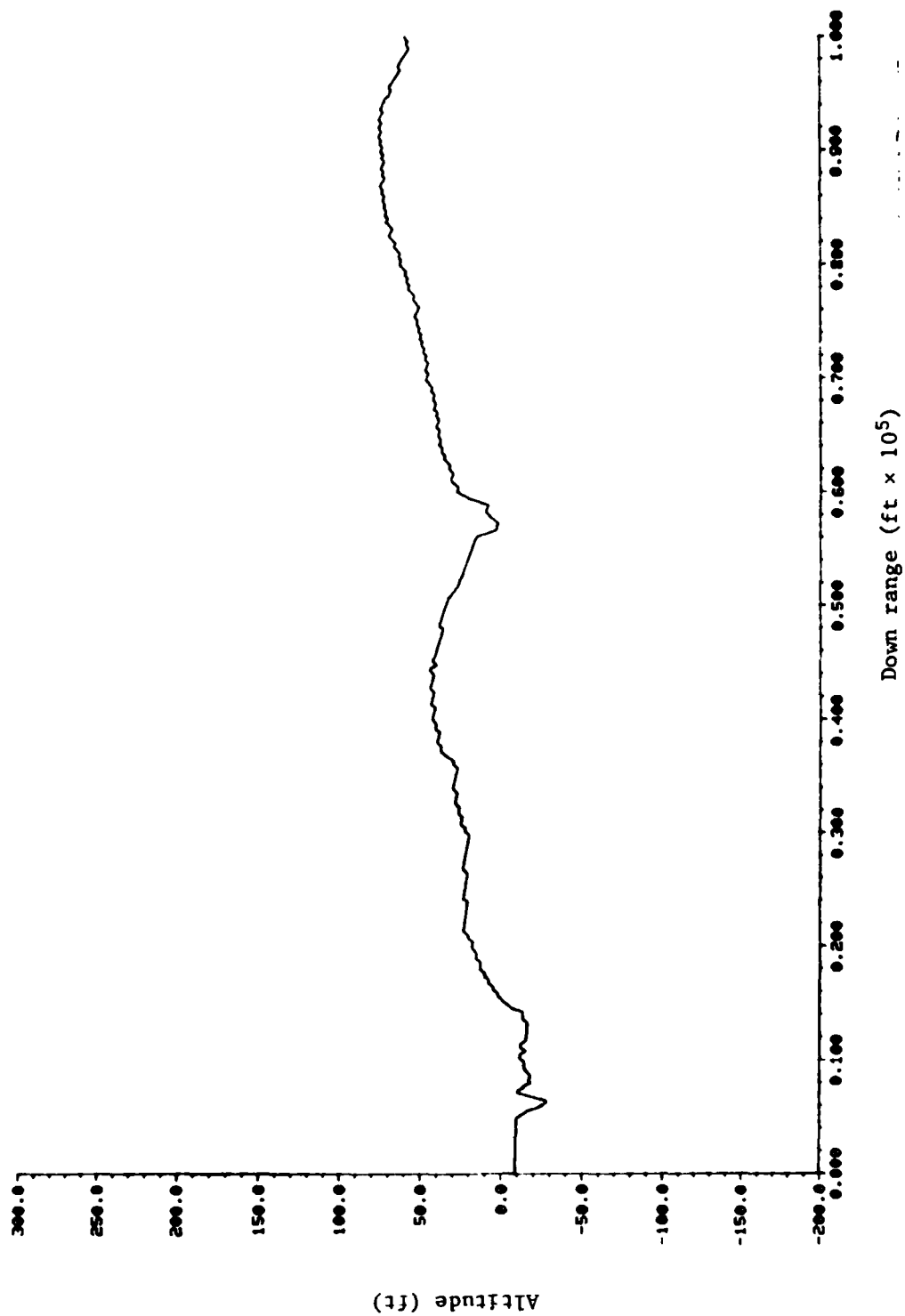


Figure 34. WC 50 elevation profile, 55° azimuth, 9-foot radar height.

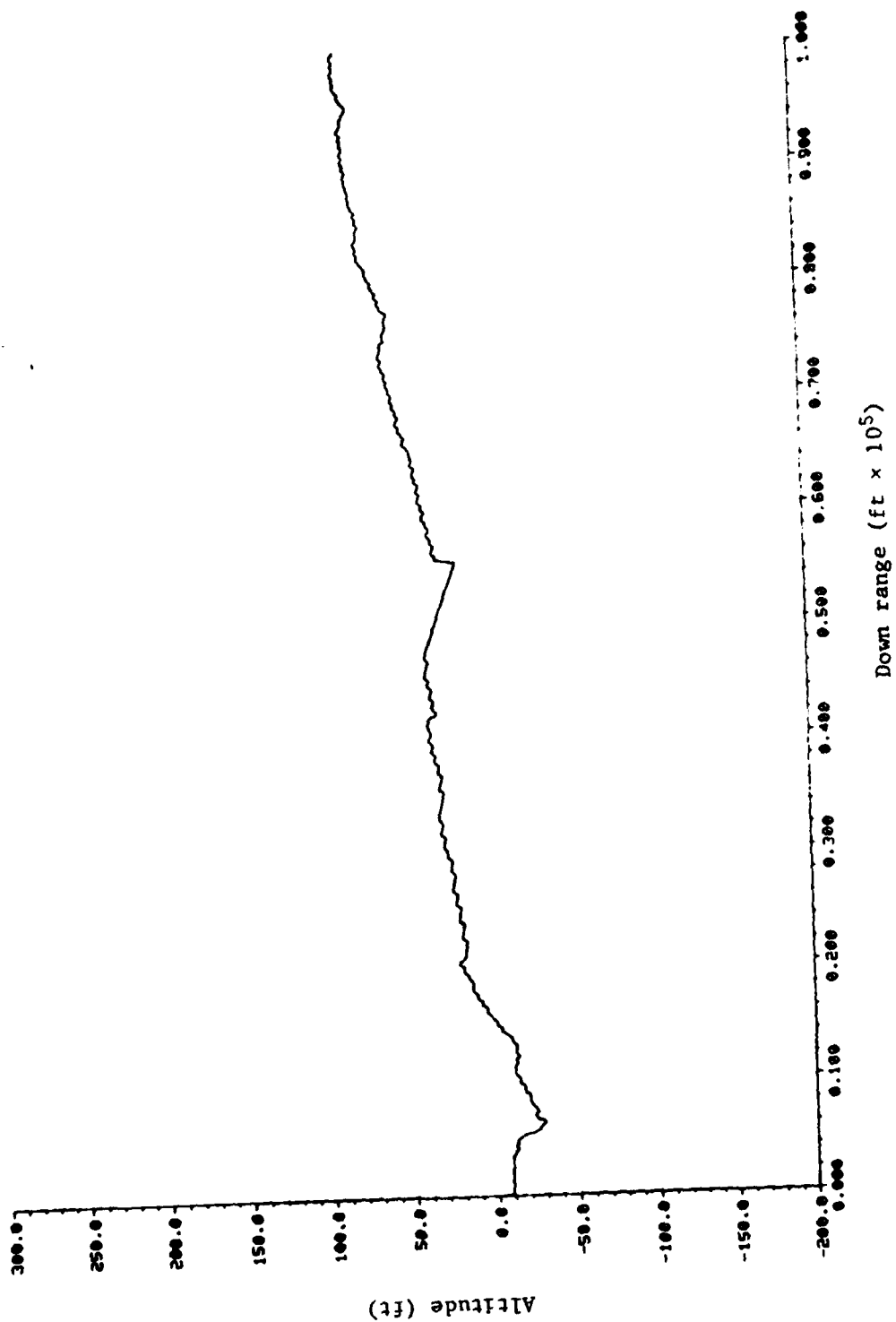


Figure 35. WC 50 elevation profile, 60° azimuth, 9-foot radar height.

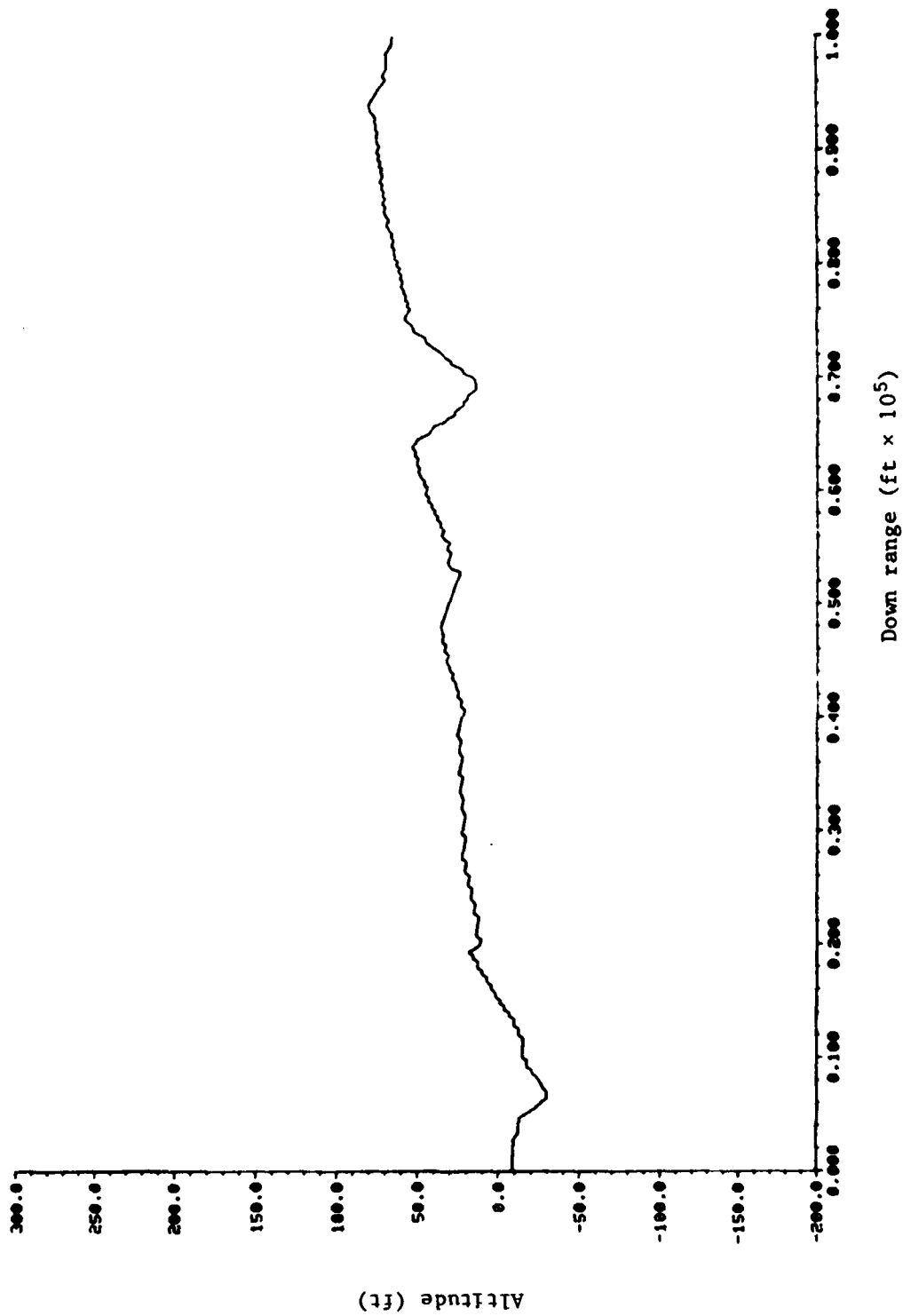


Figure 36. WC 50 elevation profile, 65° azimuth, 9-foot radar height.

#### REFERENCES

1. Sellers, Jr., W. R., and B. G. Gibbs, "Descriptions of General Purpose Computer Subroutines," TR-WS-79, April 1979.
2. Wright, J. W., "High Level Plotting Programs for the Houston Instruments Model DP-3 Plotter and the Tektronix 4014 Graphic Terminal," (in publication).
3. Wright, J. W., Private Communication.

APPENDIX  
COMPUTER PROGRAMS



Several computer programs were developed in the process of evaluating approaches and performing the analysis. In general, the tasks of transformation, interpolation, and masking are the significant steps. Since the transformation programs are documented in the reference they will not be repeated here. The only note of caution to the prospective user is that the sense of the various coordinate systems must be clearly understood.

The interpolation and masking steps will be represented by an example program. This routine used as input on Tape 10 data already transformed to radar tangent plane. The program selects a radial for analysis and interpolates data points in 50-foot increments via subroutine TINTER. After creation of the radial elevation profile, subroutine MASKK is called to do the masking calculations. Start and end points of illumination are connected by a solid line and plotted using subroutine PLTTEK. This utility to produce CRT displays of the data is also documented in the references and not included here.

Outputs from this program include the CRT display of illuminated regions with the same data stored on magnetic tape (TAPE 2) and significant comments concerning the results on OUTPUT.

This description is intended to give the flavor of the computations rather than an exhaustive description. No extensive attempt was made to maximize the computational speed or efficiency of these programs. If their use is contemplated in a production environment, such improvements should definitely be considered.

PROGRAM MASK

1	PROGRAM MASK(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT, TAPF10,TAPE1,TAPE2)	000410 000420 000430 000440
5	DIMENSION IHEAD(10),XA(340),YA(340),ZA(340),XB(340),YB(340), ZB(340),H(2000),O(2000) DIMENSION LZ(2) DATA PI/3.14159/	000450 000460 000470 000480 000490
10	WRITE 11 FORMAT(1H1) READ(10)IHEAD WRITE(2)IHEAD WRITE 1,IHEAD FORMAT(1X,10A10)	000500 000510 000520 000530 000540 000550
	1 C C ANGLE IN DEGREES C	000560 000570 000580 000590
20	READ 2,THRAY,H0,CUTS FORMAT(3F10,2) WRITE 2,THRAY,H0,CUTS ICUTS=CUTS+.5 WRITE(2)THRAY,H0,CUTS	000600 000610 000620 000630 000640
25	C C DO 109 I=1,2000 R(I)=(I-1)*50. LZ(2)=10H* THRAY0=THRAY N340=340 N2000=2000 LX=10HRANGE FT* LY=10HALT TP*	000650 000660 000670 000680 000690 000700 000710 000715 000716 000717
35	C C XMN=0. YMN=YMx XMX=100000. DO 500 IRAY=1,ICIITS DO 12 I=2,2000 M(I)=0. THRAY=THRAY0+(IRAY-1)*1. REWIND 10 READ(10)IHEAD THRAYD=THRAY THRAY=THRAY*PI/180. TANTH=TAN(THRAY) COSTHR=COS(THRAY) SINTHR=SIN(THRAY) M(I)=0. P(I)=0. WRITE 10,IRAY,THRAYD FORMAT(/,1X,*IRAY = *.14,* THRAYD = *.F10,2) DO 3 I=1,200 IY=I READ(10)XA,YA,7A	000720 000730 000740 000750 000760 000770 000780 000790 000800 000810 000820 000830 000840 000850 000860 000870 000880 000885 000886 000890 000900 000910

PROGRAM MASK

		IF(YA(1).LT.0.)GO TO 4	000920
	3	CONTINUE	000930
60	4	CONTINUE	000940
		BACKSPACE 10	000950
		IY=IY-1	000960
		IX=1	000970
		YA(1)=YB(1)	000980
65		WRITE 60,IY	000990
	60	FORMAT(* 7ERO COLUMN = *.15)	001000
		DO 110 I=2,2000	001010
		PX=(I-1)*50.	001020
		XD=RX*COSTHR	001030
70		YD=PX*SINTHR	001040
		IF(YD.GT.YB(IX).AND.YD.LT.YA(IX))GO TO 102	001050
		DO 5 J=1,200	001060
		JY=J	001070
		READ(10)XA,YA,ZA	001080
75		IF(EOF(10))1000,100	001090
	100	CONTINUE	001100
		IF(YA(IX).LT.YD)GO TO 6	001110
	5	CONTINUE	001120
	6	CONTINUE	001130
80		IY=IY+JY	001140
		BACKSPACE 10	001150
		BACKSPACE 10	001160
		READ(10)XA,YA,ZA	001170
		IF(EOF(10))1000,101	001180
85	101	CONTINUE	001190
		READ(10)XB,YB,ZB	001200
		IF(EOF(10))1000,102	001210
	102	CONTINUE	001220
		IF(I.LT.2)WRITE 61,IY,I	001230
90	61	FORMAT(* COLUMN *.15.* CHOSEN FOR PASS *.15)	001240
		DO 7 J=1,350	001250
		JX=J	001260
		IF(XA(J).GT.XD)GO TO 8	001270
	7	CONTINUE	001280
95	8	CONTINUE	001290
		IX=JX-1	001300
		IYY=IY-1	001310
		CALL TINTER(XA,YA,ZA,XB,YB,ZB,IX,IYY,XD,YD,H(1),N340,I)	001320
	110	CONTINUE	001330
100		GO TO 1002	001340
	1000	CONTINUE	001350
		WRITE 1001,I	001360
	1001	FORMAT(* EOF ENCOUNTERED IN PASS *.15)	001370
	1002	CONTINUE	001380
105		WRITE(2)THRAYD, N2000,R,H	001390
		CALL MASKK(R,H,2000,THRAY,TRAY,XMN,XXM,YMN,XXY)	001400
		ENCODE(10,90,LZ(1))THRAYD	001401
	90	FORMAT(F10,2)	001402
		CALL PLTTEK(R,H,2000,0,LX,LY,L7,XMN,XXM,YMN,XXY)	001403
110	500	CONTINUE	001410
	65	FORMAT(RE15,7)	001440
	150	FORMAT(F10,2)	001490
		CALL FINITT	001520
		STOP	001530
115		END	001540

SUBROUTINE MASKK

1	SUBROUTINE MASKK(R,H,NN,THCUT,IP,XMN,XX,YYN,YYX)	003210
	DIMENSION R(NN),H(NN),X(2),Y(2)	003220
	NN=0	003230
5	CCCC IF(IP.GT.1)GO TO 90	003240
	GO TO 90	003241
	YYX=ARS(YYN)	003250
	X(1)=XMN	003260
	Y(1)=YYN	003270
	LX=10HOWN RNG*	003280
10	LY=10HCROSS RNG*	003290
	LZ=10HMASK*	003300
	CALL PLTTEK(X,Y,1,NN,LX,LY,LZ,XMN,XX,YYN,YYX)	003310
	CONTINUE	003320
	90	003330
	C	003340
15	R1=R(1)	003350
	ISFT=0	003360
	TANTHX=-100.	003370
	DO 100 I=2,NN	003380
	TANTH=H(I)/R(I)	003390
20	IF(TANTH.LT.TANTHX)GO TO 101	003400
	IF(ISFT.EQ.1)R1=R(I)	003410
	TANTHX=TANTH	003420
	ISFT=0	003430
	GO TO 100	003440
25	101 CONTINUE	003450
	IF(ISFT.EQ.0)R1=R(I)	003460
	IF(ISFT.EQ.1)GO TO 100	003470
	ISFT=1	003480
	R2=R(I-1)	003490
30	X(1)=R1*COS(THCUT)	003500
	Y(1)=R1*ARS(SIN(THCUT))	003510
	X(2)=R2*COS(THCUT)	003520
	Y(2)=R2*SIN(THCUT)	003530
	Y(2)=ARS(Y(2))	003540
35	IF(R1.FQ.R2)WRITE 60,R1,R2,IP,1,THCUT	003550
	CCCC CALL PLTTEK(X,Y,-2,NN)	003560
	100 CONTINUE	003570
	60 FORMAT(* ERROR IN MASK *,2F12.2,2I4,F10.2)	003580
	RETURN	003590
40	END	003590

SUBROUTINE TINTER

1	SUBROUTINE TINTER(XA,YA,ZA,XR,YR,ZR,IX,IY,XD,YD,ZZ,NN,1)	001550
	DIMENSION XA(NN),YA(NN),ZA(NN),XR(NN),YR(NN),ZR(NN)	001560
	DELX=XA(IX+1)-XA(IX)	001570
	DELY1=YR(IX)-YA(IX)	001580
5	DELY2=YR(IX+1)-YA(IX+1)	001590
	DY1=YD-YA(IX)	001600
	DY2=YD-YA(IX+1)	001610
	AA1=(ZR(IX)-ZA(IX))*DY1/DELY1+ZA(IX)	001620
	AA2=(ZR(IX+1)-ZA(IX+1))*DY2/DELY2+ZA(IX+1)	001630
10	DX=XD-XA(IX)	001640
	ZZ=(AA2-AA1)*DX/DELX+AA1	001650
	IF(ZZ.LT.-1000.)WRITE 2,IX,IY,XA(IX),XA(IX+1),XR(IX),XR(IX+1),	001651
	YA(IX),YA(IX+1),YR(IX),YR(IX+1),	001652
	ZA(IX),ZA(IX+1),ZR(IX),ZR(IX+1),	001653
15	DELX,DELY1,DELY2,DY1,DY2,AA1,AA2,DX,ZZ	001654
2	FORMAT(IX,2I5,12F9.1,/,1X,9F12.4)	001655
	IF(XD.LT.XA(IX).OR.XD.GT.XA(IX+1))WRITE 10,IX,IY,	001660
	AA1,AA2,XA(IX),XA(IX+1),XD,I	001670
10	FORMAT(* FIRST ERROR *,2I5,5E15.7,* PASS *,I5)	001680
20	IF(XD.LT.XR(IX).OR.XD.GT.XR(IX+1))WRITE 11,IX,IY,	001690
	AA1,AA2,XR(IX),XR(IX+1),XD,I	001700
11	FORMAT(* SECOND ERROR *,2I5,5E15.7,* PASS *,I5)	001710
	IF(YD.GT.YA(IX).OR.YD.LT.YR(IX))WRITE 12,IX,IY,AA1,AA2,	001720
	YA(IX),YR(IX),YD,I	001730
25	FORMAT(* THIRD ERROR *,2I5,5F15.7,* PASS *,I5)	001740
12	IF(YD.GT.YA(IX+1).OR.YD.LT.YR(IX+1))WRITE 13,IX,IY,AA1,AA2,	001750
	YA(IX+1),YR(IX+1),YD,I	001760
13	FORMAT(* FORTH ERROR *,2I5,5F15.7,* PASS *,I5)	001770
	RETURN	001780
30	END	001790

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